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RICHTER'S ORGANIC CHEMISTRY

VOLUME II OF THIS WORK INCLUDES THE CARBOCYCLIC
AND VOLUME III. THE HETEROCYCLIC SERIES

ORGANIC CHEMISTRY

OR

CHEMISTRY OF THE CARBON COMPOUNDS

BY

VICTOR von RICHTER

Edited by Prof. R. Anschütz and Prof. G. Schroeter

VOLUME I

CHEMISTRY OF THE ALIPHATIC SERIES

NEWLY TRANSLATED AND REVISED FROM THE GERMAN EDITION
(AFTER PROF. EDGAR F. SMITH'S THIRD AMERICAN EDITION)
BY
PERCY E. SPIELMANN, Ph.D., B.Sc., F.I.C., A.R.C.Sc.

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PREFACE TO THE FIRST ENGLISH EDITION

A COMPARISON between the present work, the latest edition of the German original, and the last American translation, will show that while the German text-book has been faithfully followed, modifications have been introduced which will be regarded, it is hoped, in the light of solid improvement. Certain statements have been corrected or modified, changes which have usually been indicated, and a great number of minor alterations have been made in the marshalling of facts and the setting out of formulæ with the object of a more logical sequence and a clearer emphasis of the point under discussion.

References to German literature have been retained with the object of preserving to the student the advantages of the origin of the book; the English references will be otherwise readily obtainable by him.

I take great pleasure in expressing my gratitude to Mr. W. P. Skertchly, F.I.C., not only for assistance in the more mechanical part of the translation, but also for the careful way in which he has read through the proofs.

Furthermore, to Mr. A. J. Greenaway, Sub-Editor of the *Journal of the Chemical Society*, I offer my most cordial thanks for his valued advice on certain doubtful points of nomenclature.

PERCY E. SPIELMANN.

LONDON, 1915.

N.B.—The Publishers beg to explain that a year's delay has occurred in the production of this volume (announced for the autumn of 1914), owing to Dr. Spielmann's employment on important work connected with explosives for the Government.

K. P. T. T. & Co., LTD.

PREFACE TO THE SECOND ENGLISH EDITION

NOTWITHSTANDING the depletion of students from the many Technical Institutions as a result of the late war, a second edition of the first volume of this text-book has been called for—a gratifying recognition of its continued and increasing usefulness.

As inevitable to the first production of a book of this character, with its innumerable formulæ and figures, a certain number of misprints had crept in, and a careful search for these has been made.

The need of such rectifications must not deter me from paying a tribute to the printers, Messrs. Clowes and Sons, for the care and success with which they have carried through so complicated a piece of type setting; while to the Publishers is due acknowledgment for much that was of assistance in my share of the work of production.

It is believed that, in its revised form, this volume will be found to meet all the requirements of the daily expanding class of chemical students, on whose services will depend so important a share in the scientific foundation of the firm establishment and success of British Industry.

PERCY E. SPIELMANN.

LONDON, 1919.

PREFACE TO THE THIRD AMERICAN EDITION

In presenting this translation of the eighth German edition of v. Richter's "Organic Chemistry" the writer has little to add to what has previously been expressed in the prefaces to the preceding American editions of this most successful book. The student of the present edition will, however, very quickly discover that the subject-matter, so ably edited by Professor Anschütz, is vastly different from that given in the earlier editions. Indeed, the book has sustained very radical changes in many particulars, and certainly to its decided advantage. The marvellous advances in the various lines of synthetic organic chemistry have made many of the changes in the text absolutely necessary, and for practical reasons it has seemed best to issue this new edition in two volumes.

Eminent authorities, such as Profs. v. Baeyer, E. Fischer, Waitz, Claisen, and others, have given the editor the benefit of their supervision of chapters relating to special fields of investigation in which they are the recognized authorities.

The translator here acknowledges his great indebtedness to his publishers, P. Blakiston's Son & Co., for their constant aid in his work, as well as to Messrs. Wm. F. Fell & Co., for the care they have taken and the skill they have displayed in the composition of what will generally be admitted to be a difficult piece of typography.

E. F. SMITH.

PREFACE TO THE SECOND AMERICAN EDITION

The present American edition of v. Richter's "Organic Chemistry" will be found to differ very considerably, in its arrangement and size, from the first edition. The introduction contains new and valuable additions upon analysis, the determination of molecular weights, recent theories on chemical structure, electric conductivity, etc. The section devoted to the carbohydrates has been entirely rewritten, and presents the most recent views in regard to the constitution of this interesting group of compounds. The sections relating to the trimethylene, tetramethylene, and pentamethylene series, the furfurane, pyrrol, and thiophene derivatives, have been greatly enlarged, while the subsequent chapters, devoted to the discussion of the aromatic compounds, are quite exhaustive in their treatment of special and important groups. Such eminent authorities as Profs. Ostwald, von Baeyer, and Emil Fischer have kindly supervised the author's presentation of the material drawn from their special fields of investigation.

The characteristic features of the first edition have been retained, so that the work will continue to be available as a text-book for general class purposes, useful and reliable as a guide in the preparation of organic compounds, and well arranged and satisfactory as a reference volume for the advanced student as well as for the practical chemist.

The translator would here express his sincere thanks to Prof. v. Richter, whose hearty co-operation has made it possible for him to issue this translation so soon after the appearance of the sixth German edition.

E. F. SMITH.

PREFACE TO THE FIRST AMERICAN EDITION

THE favourable reception of the American translation of Prof. von Richter's "Inorganic Chemistry" has led to this translation of the "Chemistry of the Compounds of Carbon," by the same author. In it will be found an unusually large amount of material, necessitated by the rapid advances in this department of chemical science. The portions of the work which suffice for an outline of the science are presented in large type, while in the smaller print is given equally important matter for the advanced student. Frequent supplementary references are made to the various journals containing original articles, in which details in methods and fuller descriptions of properties, etc., may be found. The volume thus arranged will answer not only as a text-book, and indeed as a reference volume, but also as a guide in carrying out work in the organic laboratory. To this end numerous methods are given for the preparation of the most important and the most characteristic derivatives of the different classes of bodies.

E. F. SMITH.

ABBREVIATIONS

A.	Liebig's Annalen der Chemie. Spl.—Supplementband.
A. chim. phys.	Annales de chemie et de physique.
Am.	American Chemical Journal.
Anorg. Ch.	Richter-Klinger, Lehrbuch der anorganischen Chemie. Richter-Smith, Text-book of Inorganic Chemistry.
Arch. exp. Path.	Archiv für experimentelle Pathologie und Pharmakologie.
Arch. ges. Phys.	Archiv für die gesammte Physiologie.
$[\alpha]_D$	Specific optical rotation.
B.	Berichte der deutschen chemischen Gesellschaft. R = Referate.
Bp.	Boiling point. Bp_{10} = Boiling point at 10 mm. pressure of mercury.
Bull. soc. chim.	Bulletin de la société chimique de Paris.
C.	Chemisches Centralblatt.
Ch. Ztg.	Chemiker-Zeitung.
C.r.	Comptes rendus des séances de l'Académie des sciences.
D.	Density, specific gravity, D_{20}= Sp. gr. at 20° C.
Δ^1, Δ^2, Δ^3, *etc.*	Denotes the position of a double linkage in a carbon chain, reckoned from the C-atom 1, 2, 3, etc. to the next higher member.
D. R. P.	Deutsches Reichspatent.
Gaz. chim. ital.	Gazetta chimica italiana.
F. Hdw.	Fehling's Handwörterbuch für Chemie.
J.	Jahresbericht für die Fortschritte der Chemie.
J. Chem. Soc.	Journal of the Chemical Society.
J. pr. Ch., or J. pr. Ch. N. F.	Journal für praktische Chemie. Neue Folge.
L. Hdw.	Ladenburg's Handwörterbuch für Chemie.
M.	Monatshefte für Chemie.
Pharm. Centr.	Pharmaceutische Centralhalle.
Phil. Mag.	Philosophical Magazine.
Pogg. A., or Wied. A.	Annalen der Physik und Chemie, published by Poggendorf; or new series, published by Wiedemann.
R.	*See* B.
R. Meyer's J.	Richard Meyer's Jahrbuch der Chemie.
Wied. A.	*See* Pogg. A.
Wien. Monatsh.	Monatsheft für chemie (Vienna).
Z.	Zeitschrift für Chemie.
Z. anal. Ch.	Zeitschrift für analytische Chemie.
Z. angew. Ch.	Zeitschrift für angewandte Chemie.
Z. anorg. Ch.	Zeitschrift für anorganische Chemie.
Z. Electroch.	Zeitschrift für Electrochemie.
Z. Kryst.	Zeitschrift für Krystallographie und Mineralogie.
Z. phys. Ch.	Zeitschrift für physicalische Chemie.
Z. physiol. Ch.	Hoppe-Seyler's Zeitschrift für physiologische Chemie.

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A TEXT-BOOK

OF

ORGANIC CHEMISTRY

INTRODUCTION

Whilst *inorganic chemistry* was developed primarily through the investigation of minerals, and was in consequence termed *mineral chemistry*, it may be said that the development of *organic* chemistry was due to the study of products resulting from the alteration of plant and animal substances. About the close of the eighteenth century *Lavoisier* demonstrated that, when the organic substances present in vegetable and animal organisms were burned, carbon dioxide and water were always formed. It was this chemist also who showed that the component elements of these bodies, so different in properties, were generally carbon, hydrogen, oxygen, and, especially in animal substances, nitrogen. *Lavoisier* further gave utterance to the opinion that peculiarly constituted atomic groups, or radicals, were to be accepted as present in organic substances; whilst the mineral substances were regarded by him as the direct combinations of single elements.

As it seemed impossible, for a long time, to prepare organic bodies synthetically from the elements, the opinion prevailed that there existed an essential difference between organic and inorganic substances, which led to the use of the names *Organic Chemistry* and *Inorganic Chemistry*. The prevalent opinion was, that the chemical elements in the living bodies were subject to other laws than those in the so-called inanimate nature, and that the organic substances were formed in the organism only by the intervention of a *peculiar vital force*, and that they could not possibly be prepared in an artificial way.

One fact sufficed to prove these rather restricted views to be unfounded. The first organic substance artificially prepared was urea (*Wöhler*, 1828). By this synthesis chiefly, to which others were soon added, the idea of a peculiar force necessary to the formation of organic compounds was contradicted. All further attempts to separate organic substances from the inorganic (the chemistry of the simple and the chemistry of the compound radicals, p. 18) were futile. At present we know that these do not differ essentially from each other;

that the peculiarities of organic compounds are dependent solely on the nature of their essential constituent, Carbon ; and that many substances belonging to plants and animals can be prepared artificially from the elements. *Organic Chemistry* is, therefore, the *chemistry of the carbon compounds.* Its separation from the chemistry of the other elements is necessitated only by practical considerations, on account of the very great number of carbon compounds (about 120,000: see M. M. Richter's Lexikon der Kohlenstoffverbindungen), which far exceeds those of all other elements put together. No other possesses in the same degree the ability of the carbon atoms to unite with one another to form open and closed rings or chains. The numerous existing carbon nuclei in which atoms or atomic groups of other elements have entered in the formation of organic derivatives have arisen in this manner.

The impetus given to the study of the compounds of carbon has not only brought new industries into existence, but it has caused the rapid development of others of like importance to the growth and welfare of the nation.*

The advances of organic chemistry are equally important to the investigation of the chemical processes in vegetable and animal organisms, a section of the subject known as *Physiological Chemistry.*

DETERMINATION OF THE COMPOSITION OF CARBON COMPOUNDS

ELEMENTARY ORGANIC ANALYSIS

Most carbon compounds occurring in the animal and vegetable kingdoms consist of carbon, hydrogen, and oxygen, as was demonstrated by *Lavoisier,* the founder of organic elementary analysis. Many, also, contain nitrogen, and on this account these elements are termed *Organogens,*† whilst sulphur and phosphorus are often present. Almost all the elements, non-metals and metals, may be artificially introduced as constituents of carbon compounds in direct union with carbon. The number of known carbon compounds is exceedingly great (see above). The general procedure, therefore, of isolating the several compounds of a mixture, as is done in inorganic chemistry in the separation of bases from acids, is impracticable, and special methods have to be devised. The task of elementary organic analysis is to determine, qualitatively and quantitatively, the elements of a carbon compound after it has been obtained in a pure state and characterized by definite physical properties, such as crystalline form, specific gravity, melting point, and boiling point. Simple practical methods for the direct determination of oxygen do not exist ; its quantity is usually calculated by difference, after the other constituents have been found.

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* Wirthschaftliche Bedeutung chemischer Arbeit, von H. Wichelhaus, 1893.

† This word is retained here from the German, but is not in general use in English chemical language. (Translator's note.)

DETERMINATION OF CARBON AND HYDROGEN

The presence of carbon in a substance is shown by its charring when ignited out of contact with air. In general its quantity, as also that of the hydrogen, is ascertained by combustion. The substance is mixed in a glass tube with copper oxide and heated, or the vapour of the substance is passed over red-hot copper oxide. The cupric oxide gives up its oxygen and is reduced to metallic copper, whilst the carbon burns to carbon dioxide, and the hydrogen to water. In quantitative analysis, these products are collected separately in special apparatus, and the increase in the weight of the latter determined. Carbon and hydrogen are always simultaneously determined in one operation. The details of the quantitative analysis are fully described in the text-books of analytical chemistry.* It is only necessary here, therefore, to outline the methods employed. *Liebig's* name is especially associated with the elaboration of these methods (Pogg. A. 1831, **21**, 1).

Usually the combustion is effected by the aid of copper oxide or fused and granulated lead chromate in a tube of hard glass, fifty to seventy centimetres long (depending upon the greater or less volatility of the organic body). Substances which burn with difficulty should be mixed with finely divided cupric oxide, finely divided lead chromate, or with cupric oxide to which potassium bichromate has been added.

The combustion tube is drawn into a point, and the contracted end given a bayonet-shape (*Liebig*), or it is open at both ends (*Glaser*, A. Suppl. 7, 213). *Cloez* has also suggested the use of an iron tube (Z. anal. Ch. **2**, 413).

The tube is placed in a suitable furnace, which formerly was heated by a charcoal fire, but at present gas is usually employed (*A. W. Hofmann*, A. **90**, 235; **107**, 37; *Erlenmeyer*, Sr., A. **139**, 70; *Glaser*, *l.c.*; *Anschütz* and *Kekulé*, A. **228**, 301; *Fuchs*, B. **25**, 2723). Recently electric heating has been adopted with success (comp. B. **39**, 2263).

When the tube has been charged, the open end is attached to an apparatus designed to collect the water produced in the combustion. The substances used to retain the moisture are:

1. A U-tube filled with carefully purified calcium chloride, which has been dried at 180° C.

2. Pure, concentrated sulphuric acid contained in a specially designed tube, or pumice fragments, dipped in the acid, and placed in a U-tube (*Mathesius*, Z. anal. Ch. **23**, 345).

3. Pellets of glacial phosphoric acid, contained in a U-tube. The vessel intended to receive the water is in air-tight connection with the apparatus designed to absorb the carbon dioxide. For the latter purpose a Liebig potash bulb was formerly employed, but later that of Geissler came into use; and very many other forms have been recommended (B. **24**, 271; C. 1900, **1**, 1240). U-tubes, filled with granulated soda-lime, are substituted for the customary bulbs (*Mulder*, Z. anal. Ch. **1**, 2).

When the combustion is finished, oxygen free from carbon dioxide is forced into or drawn through the combustion-tube, air being substituted for it later, with the precaution that the pieces of apparatus serving to dry the oxygen and air are filled with the same material which was used for absorbing the water produced by the combustion. As soon as the entire system is filled with air, the pieces of apparatus employed for absorbing the water and carbon dioxide are disconnected and weighed separately. The increase in weight of the apparatus in which the water is collected represents the water resulting from the combustion of the

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* Anleitung zur Analyse organischer Körper, J. Liebig. 2. Aufl. 1853. Quantitative chemische Analyse, R. Fresenius. 6. Aufl., Bd. 2. Chemische Analyse organischer Stoffe, von Vortmann. Die Entwicklung der organischen Elementaranalyse, M. Dennstedt, 1899.

weighed substance, and the increase in the other the quantity of carbon dioxide. Knowing the composition of water and carbon dioxide the quantity of carbon and hydrogen contained in the burnt substance can readily be calculated in percentage.

Fig. 1 represents one end of a combustion furnace of the type devised by *Kekulé* and *Anschütz* (A. 228, 301). In it lies the combustion tube *V*. This is connected with a Klinger calcium chloride tube, *A*; *B* is a Geissler potash-bulb, joined to a U-tube, *C*, one limb of which is filled with pieces of stick potash, and the other with calcium chloride. *G* represents mica plates, which permit of a careful observation of the flame. *E* is a section of the iron tube (Modification, C. 1903, **1**, 609) in which the combustion tube *V* rests; *T* a side clay cover placed over the mica strips; *D* a clay cover for the top. *R* is the gutter into which the gas-pipe, bearing the burners, is placed, and from which it can be removed for repair, etc.

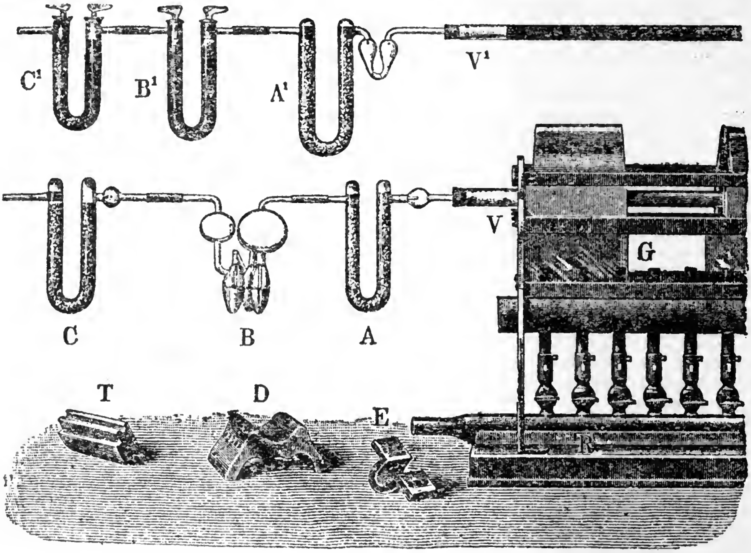

FIG. 1.

Fig. 1 also shows, above the combustion tube, the anterior portion of a similar tube V^1, provided with a Bredt and Posth (A. 285, 385) calcium chloride tube A^1, in which the movement of a drop of water enables the analyst to determine the rapidity of the combustion. B^1 is a U-tube filled with soda-lime and provided with ground-glass stoppers. C^1 is a similar tube, filled one-half with soda-lime and one-half with calcium chloride.

Instead of oxidizing the organic substance with the combined oxygen of cupric oxide or lead chromate, the method of *Kopfer* may be employed, in which platinum black is made to carry free oxygen to the vapours of the substance. A simpler combustion furnace may then be employed.

This method has been perfected by *Dennstedt*[*] and his co-workers. In his "rapid combustion method" the substance is introduced into a small tube and vapourized therefrom into a slow stream of oxygen. At the same time a more rapid current of the gas is sent round the small containing tube and over the heated contact substance (thin strips of platinum foil), so that the vapour of the compound to be combusted is always in the presence of a large excess of oxygen. The accompanying illustration (Fig. 2) indicates clearly the arrangement (B. 38, 3729; 39, 1623).

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[*] Dennstedt, Anleitung zur vereinfachten Elementar-analyse, 2. Aufl. Hamburg, 1906.

Dudley recommends that the substance be placed in a boat and burned in a platinum tube containing granular manganese dioxide in the anterior part (B. **21**, 3172). Or the substance may be combusted in a drawn-out copper tube (C. 1898, **2**, 305).

Methods for the complete combustion of solid carbon compounds have been worked out by *W. Hempel, Krocker*, as well as by *Zuntz* and *Frentzel* (B. **30**, 202, 380, 605), by which the substance is completely burned in oxygen under pressure in an autoclave.

Gaseous bodies can be analysed according to the usual gas analysis methods, either with *Bunsen's* * apparatus, or with *Hempel's*,† when great accuracy is not required. The volume of the gas or mixture of gases is measured after each successive reaction with potassium hydroxide solution, fuming sulphuric acid, alkaline pyrogallic acid and ammoniacal cuprous chloride. These reagents absorb respectively carbon dioxide, the so-called heavy hydrocarbons (olefines, acetylene, aromatic hydrocarbons of the C_nH_{2n-6} series), oxygen and carbon monoxide. The gaseous residue, which may consist of nitrogen, hydrogen and methane, is either exploded with oxygen and the contraction in volume measured both before and after absorption of the carbon dioxide formed; or else the two combustible gases may be separately dealt with, the hydrogen being absorbed by paladium black and the methane being led over incandescent platinum. A complete separation of the ethylene hydrocarbons from those of the benzene series has often been attempted, but the results have not been satisfactory.

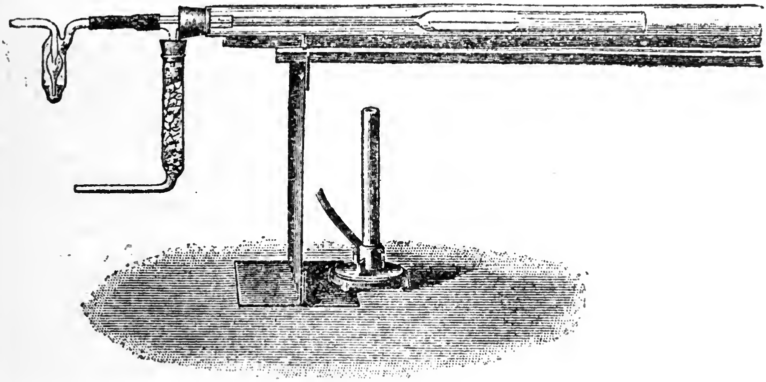

FIG. 2.

When *nitrogen* is present in the substances burned, its oxides are sometimes produced, which have to be reduced to nitrogen. This may be effected by conducting the gases of the combustion over a layer of metallic copper filings, or a roll of copper gauze placed in the front portion of the combustion tube. The latter, in such cases, should be a little longer than usual. The copper, which has been previously reduced in a current of hydrogen, often includes some of the gas which, on subsequent combustion, would yield water. To remedy this, the copper after reduction is heated in an air-bath or, better, in a current of carbon dioxide or to 200° in a vacuum. Its reduction by the vapours of formic acid or methyl alcohol is more advantageous; this may be done by pouring a small quantity of these liquids into a dry test tube and then suspending in them the roll of copper heated to redness; copper thus reduced is perfectly free from hydrogen.

It is generally unnecessary to use a copper spiral when the combustions are carried out in open tubes.

If the substance contains *chlorine, bromine* or *iodine*, copper halides are formed, which, being volatile, would pass into the calcium chloride tube. In order to avoid this a spiral of thin copper, or better, silver foil is introduced into the front

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* Bunsen, Gasometrische Methoden, 2. Aufl. Braunschweig, 1877.

† Hempel, Gasometrische Methoden, Braunschweig, 1900. Winkler, Gasanalyze, Freiberg, 1901.

part of the tube. When the organic compound contains *sulphur* a portion of the latter will be converted into sulphur dioxide (during the combustion with cupric oxide), which may be prevented from escaping by introducing a layer of lead peroxide (Z. anal. Ch. **17**, 1). Or lead chromate may be substituted for the cupric oxide, which would convert the sulphur into non-volatile lead sulphate. In the combustion of organic salts of the alkalies or alkaline earths, a portion of the carbon dioxide is retained by the base. To prevent this and to expel the CO_2, the substance in the boat is mixed with potassium bichromate or chromic oxide (B. **13**, 1641).

An organic substance, containing nitrogen, sulphur, chlorine or bromine, can be analysed by *Dennstedt's* method (see above, Fig. 1). It is mixed with pure lead peroxide and placed in a boat of special shape in the front part of the tube. The temperature is then raised to about 320°. The nitrogen, sulphur, and halogens are held back in the form of lead compounds, whilst the carbon and hydrogen pass away as carbon dioxide and water, and are estimated in the usual way.

When carbon alone is to be determined this can be effected, in many instances, in the wet way, by oxidation with chromic acid and sulphuric acid (*Messinger*, B. **21**, 2910; compare A. **273**, 151).

DETERMINATION OF NITROGEN

In many instances, the presence of nitrogen is disclosed by the odour of burnt feathers when the compounds under examination are heated. Many nitrogenous substances yield ammonia when heated with alkalies (or, better still, with soda-lime). A simple and very delicate test for the detection of nitrogen is the following: the substance is heated in a test tube with a small piece of sodium or potassium, or, when the substance is explosive, with the addition of dry soda. Potassium cyanide is produced, accompanied perhaps by a slight detonation. The residue is treated with water; to the filtrate, ferrous sulphate containing a ferric salt is added, and then a few drops of potassium hydroxide; the mixture is then heated, and finally an excess of hydrochloric acid is added. An undissolved, blue-coloured precipitate (Prussian blue), or a bluish-green coloration, indicates the presence of nitrogen in the substance examined.

Nitrogen is determined quantitatively: (1) as nitrogen, by the method of *Dumas;* (2*a*) as ammonia, by the ignition of the material with soda-lime (method of *Will* and *Varrentrap*); (2*b*) as ammonia, by heating the substance with sulphuric acid according to the directions of *Kjeldahl.*

1. **Dumas' Method.**—The substance, mixed with cupric oxide, is burned in a tube of hard glass in the anterior end of which is a layer of metallic copper which serves for the reduction of the oxides of nitrogen. The tube is filled with carbon dioxide, obtained by heating either dry, primary sodium carbonate or magnesite, contained in the posterior and closed end of the tube. It can also be filled from a carbon dioxide apparatus of the type recommended by *Kreusler* (Z. anal. Ch, **24**, 440), in which case an open tube is used. A more practicable method of procedure consists in evacuating the tube, previous to the combustion, by means of an air-pump, and filling each time with carbon dioxide (A. **233**, 330, note); or the air may be removed by means of a mercury pump (Z. anal. Ch. **17**, 409).

When the combustion is ended, excess of carbon dioxide is employed to sweep all the nitrogen from the combustion tube into the graduated tube or *azotometer*, which may have one of a variety of forms (*Zulkowsky*, A. **182**, 296; B. **13**, 1099; *Schwarz*, B. **13**, 771; *Ludwig*, B. **13**, 883; *H. Schiff*, B. **13**, 885; *Staedel*, B. **13**, 2243; *Groves*, B. **13**, 1341; *Ilinski*, B. **17**, 1348). The potassium hydroxide in the graduated vessel absorbs all the disengaged carbon dioxide, and only pure nitrogen remains.

Given the volume V_t of the gas, the barometric pressure p and the vapour-pressure s of the potassium hydroxide (*Wüllner*, Pogg. A. **103**, 529; **110**, 564) at the temperature t of the surrounding air, the volume V_0 at 0° and 760 mm. may be easily deduced:

$$V_0 = \frac{V_t(p-s)}{760\ (1+0{\cdot}003665t)}.$$

Multiply V_0 by 0·0012507, the weight of 1 c.c. of nitrogen at 0° and 760 mm., and the product will represent the weight in grams of the observed volume of nitrogen:

$$G = \frac{V_t(p-s)}{760\ (1+1{\cdot}003665\,t)} \times 0{\cdot}0012507$$

from which the percentage of nitrogen in the substance analysed can easily be calculated.

Instead of reducing the observed gas volume V, from the observed barometric pressure and the temperature at the time of the experiment, to the normal pressure of 760 mm. and the temperature of 0° ("N.T.P."), the reduction may be more readily effected by comparing the observed volume of gas or vapour with the expansion of a normal gas-volume (100) measured at 760 mm. and 0°. For this purpose the equation $V_0 = V.\frac{100}{v}$ is employed, in which v represents the changed normal volume (100). The gas-volumometer recommended by *Kreusler* (B. **17**, 30) and *Winkler* (B. **18**, 2534), or the *Lunge nitrometer* (B. **18**, 2030; **23**, 440; **24**, 1656, 3491; *J. A. Müller*, B. **26**, R. 388) will answer very well for this purpose. Or the nitrogen may be collected in a *gas-baroscope*, and its weight calculated from the pressure of a known constant volume of nitrogen (B. **27**, 2263).

Frankland and *Armstrong* conduct the combustion in a vacuum, and dispense with the layer of metallic copper in the anterior portion of the tube. If any nitric oxide is formed it is collected together with the nitrogen, and is subsequently removed by absorption (B. **22**, 3065).

Consult *Hempel* (Z. anal. Ch. **17**, 409); *E. Pfluger* (*ibid.*, **18**, 296); and *Jannasch* and *V. Meyer* (A. **233**, 375), for methods by which carbon, hydrogen, and nitrogen are determined simultaneously.

See *Gehrenbeck* (B. **22**, 1694) when nitrogen and hydrogen are to be estimated simultaneously, in cases where the carbon was determined in the wet way, as by *Messinger's* method.

For the simultaneous determination of carbon and nitrogen, see *Klingemann* (A. **275**, 92).

2. **Will and Varrentrap's Method.**—When most nitrogenous organic compounds (nitro-derivatives excepted) are ignited with alkalies, all the nitrogen is eliminated in the form of ammonia gas. The weighed, finely pulverised substance is mixed with about 10 parts soda-lime, and placed in a combustion tube about 30 cm. in length, which is then filled with soda-lime. At the open end of the tube there is connected a bulb apparatus, containing dilute hydrochloric acid. The anterior portion of the tube in the furnace is first heated, then that containing the mixture. In order to carry all the ammonia into the bulb, air is passed through the tube, after the fused-up end has been broken. The ammonium chloride in the hydrochloric acid is precipitated with platinic chloride, as ammonium-platinum chloride ($PtCl_4 . 2NH_4Cl$); the precipitate is then ignited, and the residual Pt weighed; 1 atom of Pt corresponds to 2 molecules of NH_3 or 2 atoms of nitrogen.

Or, having employed a definite volume of acid in the apparatus, the excess after the ammonia absorption may be determined volumetrically, using fluorescein or methyl orange as an indicator.

Generally, too little nitrogen is obtained by this method, because a portion of the ammonia undergoes decomposition. This is avoided by adding sugar to the mixture of substance and soda-lime, and by avoiding heating the tube too strongly (Z. anal. Ch. **19**, 91). Further, the tube must be filled with soda-lime as completely as possible (Z. anal. Ch. **21**, 278).

The method of *Will* and *Varrentrap* is made more widely applicable by the addition of reducing substances to the soda-lime. *Goldberg* (B. **16**, 2549) recommends a mixture of soda-lime (100 parts), stannous sulphide (100 parts), and sulphur (20 parts); this he considers especially advantageous in estimating the nitrogen of nitro- and azo-compounds. For nitrates, *Arnold* (B. **18**, 806) employs a mixture of soda-lime (2 parts), sodium thiosulphate (1 part), and sodium formate (1 part).

3. **Kjeldahl's Method.**—The substance is dissolved by heating it with concentrated sulphuric acid. This decomposes the organic matter and converts the nitrogen into ammonia. After the liquid has been diluted with water and cooled, and a small quantity of potassium permanganate has been added, the ammonia is expelled from it by boiling with sodium hydroxide (Z. anal. Ch. **22**, 366). This method is well adapted for the determination of the nitrogen of plants and animal substances (compare urea). When the nitrogen in nitro- and cyanogen compounds is to be estimated, sugar must be added; and in the case of nitrates, benzoic acid. The addition of mercury or mercuric oxide is highly advantageous (B. **18**, R. 199, 297; **29**, R. 146). Pyridine and quinoline cannot be analysed by this method (B. **19**, R. 367, 368).

The Kjeldahl method for the determination of nitrogen has rapidly come into favour on account of the simplicity of the operation and of the apparatus, and of the possibility to carry out a number of determinations simultaneously. A large number of modifications of the method have been proposed to render it generally applicable (B. **27**, 1633, **28**, R. 937; C. 1898, **2**, 312).

NOTE.—The nitrogen of nitro- and nitroso-compounds can be determined indirectly with a standardized solution of stannous chloride. The latter converts the groups NO_2 and NO into the amide group, and is itself converted into an equivalent quantity of stannic chloride. This can be determined by titrating the excess of stannous salt with an iodine solution (*Limpricht*, B. **11**, 40).

DETERMINATION OF THE HALOGENS, SULPHUR, AND PHOSPHORUS

Qualitative Analysis: Substances containing *chlorine*, *bromine* and *iodine* burn with a flame having a green-tinged border. The following reaction is exceedingly delicate. A little cupric oxide is first ignited on a platinum wire, then some of the substance to be examined is placed upon it, and the whole is heated in the non-luminous gas flame, which is coloured an intense greenish-blue if a halogen is present. A more definite test is to ignite the substance in a test tube with burnt lime (free from halogens), dissolve the mass in nitric acid, and then to add silver nitrate to the filtered solution.

The presence of *sulphur* can frequently be detected by fusing the substance with potassium hydroxide; potassium sulphide results, which produces a black stain of silver sulphide on a clean piece of silver; or by heating the substance with metallic sodium and testing the aqueous filtrate for sodium sulphide with sodium nitroprusside: if present, a purple-violet coloration is produced. When testing for *sulphur* and *phosphorus*, the substance is oxidized with a mixture of potassium nitrate and potassium carbonate; the resulting sulphuric and phosphoric acids are sought for by the usual methods.

Quantitative Analysis: A hard glass tube, closed at one end, and about 33 cm. in length, containing a mixture of the substance with chlorine-free lime, is heated. After cooling, its contents are dissolved in dilute nitric acid, the solution is filtered and silver nitrate is added to precipitate the halogen.

The decomposition is easier if instead of lime a mixture of lime with $\frac{1}{4}$ part sodium carbonate, or 1 part sodium carbonate with 2 parts potassium nitrate is employed; and in the case of substances volatilizing with difficulty, a platinum or porcelain crucible, heated over a gas lamp, can be used (*Volhard*, A. **190**, 40; *Scheff*, A. **195**, 293). With compounds containing iodine, iodic acid may form, which, after solution of the mass, may be reduced by sulphurous acid. The volumetric method of *Volhard* (A. **190**, 1) for estimating halogens, employing ammonium thiocyanate as indicator, is strongly to be recommended in place of the customary gravimetric method.

The same decomposition can also be effected by ignition with iron, ferric oxide, and sodium carbonate (*E. Kopp*, B. **10**, 290).

The substances containing the halogens may also be burned in oxygen. The gases are conducted over platinized quartz sand, and the products collected in suitable solutions (*Zulkowsky*, B. **18**, R. 648).

The substances may be burned in a current of oxygen, and the products conducted through a layer of pure granular lime (or soda-lime) raised to a red heat. Later, the lime is dissolved in dilute nitric acid, and the *halogens*, the *sulphuric acid* and the *phosphoric acid* may then be estimated. *Arsenic* may be determined similarly (*Brügelmann*, Z. anal. Ch. **15, 1**; **16**, 1). *Sauer* recommends collecting the sulphur dioxide, formed in the combustion of the substance, in hydrochloric acid containing bromine (*ibid.* **12**, 178). See also the simultaneous estimation of halogens and sulphur in the presence of carbon and hydrogen, by *Dennstedt's* method (p. 4).

To determine *sulphur* and the *halogens* by the method suggested by *Klason* (B. **19**, 1910), the substance is oxidized in a current of oxygen charged with nitrous vapours, and the products of combustion are conducted over rolls of platinum foil. Consult *Poleck* (Z. anal. Ch. **22**, 171) for the estimation of the sulphur contained in coal gas.

A method of frequent use for the determination of the *halogens*, *sulphur*, and *phosphorus* in organic bodies is that of *Carius* (Z. anal. Ch. **1**, 240; **4**, 451; **10**, 103); *Linnemann* (*ibid.* **11**, 325); *Obermeyer* (B. **20**, 2928).

The substance, weighed out in a small glass tube, is heated together with concentrated nitric acid and silver nitrate to 150–300° C. in a sealed tube, and the quantity of the resulting silver haloid (B. **28**, R. 478, 864), sulphuric acid, and phosphoric acid determined. The furnace of *Babo* (B. **13**, 1219) is especially adapted for heating the tubes. The results by this method are not always reliable (A. **223**, 184).

The following method is more generally applicable for the estimation of sulphur and the halogens: the substance is carefully heated in a nickel crucible with a mixture of sodium and potassium carbonates and sodium peroxide. After having been melted, the product of reaction is dissolved in water and acidified with hydrochloric acid containing bromine; the sulphur is then precipitated as barium sulphate (B. **28**, 427; C. 1904, **2**, 1622, etc.).

In many instances, the *halogens* may be separated by the action of sodium amalgam on the aqueous solution of the substance, or by that of sodium on the alcoholic solution. The quantity of the resulting salt is determined in the filtered liquid (*Kekulé*, A. Suppl. **1**, 340; comp. C. 1905, **1**, 1273; B. **39**, 4056).

Sulphur and *phosphorus* can often be estimated by the wet method. The oxidation is effected by means of potassium permanganate and alkali hydroxide, or with potassium bichromate and hydrochloric acid (*Messinger*, B. **21**, 2914).

DETERMINATION OF THE MOLECULAR FORMULA [*]

The results of elementary analysis are expressed as the percentage composition of the substance thus examined; then follows the determination of the *molecular formula*.

We arrive at the simplest ratio in the number of elementary atoms

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[*] Die Bestimmung des Moleculargewichts in theoretischer und practischer Beziehung, von K. Windisch, 1892.

contained in a compound, by dividing the percentage numbers by the respective atomic weights of the elements.

Thus, the analysis of lactic acid gave the following percentage composition :—

Carbon	40·0	per cent.	
Hydrogen	6·6	,,	
Oxygen	53·4	,,	(by difference)
	100·0		

Dividing these numbers by the corresponding weights (C = 12, H = 1, O = 16), the following quotients are obtained :—

$$\frac{40·0}{12} = 3·3 \qquad \frac{6·6}{1} = 6·6 \qquad \frac{53·4}{16} = 3·3$$

Therefore, the ratio of the number of atoms of C, H, and O, in lactic acid, is as 3·3 : 6·6 : 3·3, or 1 : 2 : 1. The simplest atomic formula, then, would be CH_2O; however, it remains undetermined what multiple, if any, of this formula expresses the true composition. The lowest formula of a compound, by which is expressed the ratio of the atoms of other elements to those of the carbon atoms, is an *empirical formula.* Indeed, we are acquainted with different substances having the empirical formula CH_2O, for example, formaldehyde, CH_2O; acetic acid, $C_2H_4O_2$; lactic acid, $C_3H_6O_3$; dextrose, $C_6H_{12}O_6$, etc.

With compounds of complicated structure, the derivation of the simplest formula is, indeed, unreliable, because various formulæ may be deduced from the percentage numbers on account of the possible errors of observation. The true molecular formula, therefore, can only be ascertained by some other means. Three courses of procedure are open to us. First, the study of the chemical reactions, and the derivatives of the substance under consideration; second, the determination of the vapour density of volatile substances; and third, the examination of certain properties of the solutions of soluble substances.

(1) *Determination of the Molecular Weight by the Chemical Method*

This is applicable to all substances, but does not invariably lead to definite conclusions. It consists in preparing derivatives, analysing them and comparing their formulæ with the supposed formula of the original compound. The problem becomes simpler when the substance is either a base or an acid. Then it is only necessary to prepare a salt, determine the quantity of metal combined with the acid, or of the mineral acid in union with the base, and from this to calculate the equivalent formula. A few examples will serve to illustrate this.

The silver salt of lactic acid may be prepared (the silver salts are easily obtained pure, and generally crystallize without water) and the quantity of silver in it determined; 54·8 per cent. of silver will be found. As the atomic weight of silver = 107·7, the amount of the other constituent combined with one atom of Ag in silver lactate, may be calculated from the proportion—

$$54·8 : (100 - 54·8) :: 107·7 : x$$
$$x = 89·0.$$

Granting that lactic acid is monobasic, that in the silver salt one atom of hydrogen is replaced by silver, it follows that the molecular weight of the free (lactic) acid must = 89 + 1 = 90. Consequently the simplest empiric formula of the acid, $CH_2O = 30$, must be tripled. Hence, the molecular formula of the free acid is $C_3H_6O_3 = 90$:

C_3	= 36	40·0
H_6	= 6	6·7
O_3	= 48	53·3
	90	100·0

In studying a base, the platinum double salt is usually prepared. The constitution of these double salts is analogous to that of ammonium-platinum chloride —$PtCl_4 . 2(NH_3HCl)$—the ammonia being replaced by the base. The quantity of platinum in the double salt is determined by ignition, and calculating the quantity of the constituent combined with one atom of Pt (195·2 parts). From the number found, six atoms of chlorine and two atoms of hydrogen are subtracted, and the result is then divided by two; the final figure will be the equivalent or molecular weight of the base.

Or, the substance is subjected to reactions of various kinds, *e.g.* the substitution of its hydrogen by chlorine. The simplest formula of acetic acid, as described above, is CH_2O. By substitution three acids can be obtained from acetic acid. These, upon treatment with nascent hydrogen, revert to the original acetic acid. They are—

$C_2H_3ClO_2$—Monochloracetic Acid,
$C_2H_2Cl_2O_2$—Dichloracetic Acid, and
$C_2HCl_3O_2$—Trichloracetic Acid.

Consequently, there must be three replaceable hydrogen atoms in the acid. This would lead us to the formula $C_2H_4O_2$ for it. (Comp. also *Ladenburg:* Die Theorie der aromatischen Verbindungen (1876), p. 10.)

Knowing the molecular value of an analysed compound, it will often be necessary to multiply its *empirical* formula to obtain one which will express the number of atoms contained in the molecule. This will be the ***empirical molecular formula.***

(2) *Determination of the Molecular Weight from the Vapour Density*

This method is limited to those substances which can be volatilized without undergoing decomposition. It is based upon the law of Avogadro, according to which equal volumes of all gases and vapours at like temperature and like pressure contain an equal number of molecules. The molecular weights are, therefore, the same as the specific gravities. As the specific gravity is compared with $H = 1$, and the molecular weights with $H_2 = 2$, we ascertain the molecular weights by multiplying the specific gravity by 2. Should the specific gravity be referred to air = 1, then the molecular weight is equal to the specific gravity multiplied by 28·86 (since air is 14·43 times heavier than hydrogen).

	Molecular Weight.		Specific Gravity.	
Air	—	—	14·43	1
Hydrogen	H_2	= 2	1	0·0693
Oxygen	O_2	= 31·74	15·87	1·1060
Water	H_2O	= 17·87	8·93	0·622
Methane	CH_4	= 15·97	7·98	0·553

Experience has shown that the results arrived at by the chemical method and those obtained from the vapour density—are almost always identical. If a deviation should occur, it is invariably in consequence of the substance undergoing decomposition, or dissociation, in its conversion into vapour.

Two essentially different methods are employed in *determining the vapour density*. According to one, by weighing a vessel of known capacity filled with vapour, the weight of the latter is ascertained—method of *Dumas* and of *Bunsen;* in accordance with the other, a weighed quantity of substance is vaporized and the volume of the resulting vapour determined. In the latter case the vapour volume may be directly measured—methods of *Gay-Lussac* and *A. W. Hofmann ;* or it may be calculated from the equivalent quantity of a liquid expelled by the vapour—*displacement methods.* The first three methods, of which a fuller description may be found in more extended text-books,* are seldom employed at present in laboratories, because the method of *V. Meyer,* which is characterised by simplicity in execution, affords sufficiently accurate results for all ordinary purposes.

Method of Victor Meyer.—Determination of vapour density by *displacement of air* (B. **11**, 1867, 2253). A weighed quantity of substance is vaporized in an enclosed space, and the volume of air which it displaces is measured. Fig. 3 represents the apparatus constructed for this purpose. It consists of a narrow glass tube, ending in a cylindrical vessel, *A*. The upper, somewhat enlarged opening, *B*, is closed with an india-rubber stopper. A short capillary side tube, *C*, conducts the displaced air into the water-bath, *D*. The substance is weighed out in a small glass tube provided with a stopper, and is vaporized in *A*, the escaping air being collected in the eudiometer, *E*. The vapour-bath, used in heating *A*, consists of a wide glass cylinder, *F* (B. **19**, 1862),† whose lower, somewhat enlarged end, is closed and filled with a liquid of known boiling point. The liquid employed is determined by the substance under examination; its boiling point must be above that of the latter. Some of the liquids in use are water (100°), xylene (about 140°), aniline (184°), ethyl benzoate (213°), amyl benzoate (261°), and diphenylamine (310°).

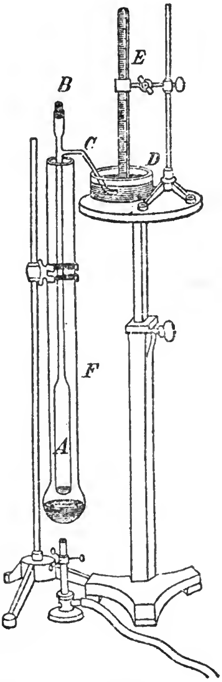

FIG. 3.

The vapour density, S, equals the weight of the vapour, P (the same, naturally, as the weight of the substance employed), divided by the weight of an equal volume of air, P′—

$$S = \frac{P}{P'}$$

1 c.c. of air at 0° and 760 mm. pressure weighs 0·001293 gram. The air volume V_t, found at the observed temperature is under the pressure $p-s$, in which p indicates the barometric pressure and s the tension of the aqueous vapour at temperature t. The weight then would be—

$$P' = 0{\cdot}001293.\ V_t.\ \frac{1}{1+0{\cdot}003673t}.\frac{p-s}{760}.$$

Consequently the vapour density sought is—

$$S = \frac{P(1+0{\cdot}003673t)760}{0{\cdot}001293.\ V_t(p-s)}.$$

The displaced air may be collected in the *gas-baroscope* (compare p. 7). (B. **27**, 2267.)

V. Meyer's method yields results that are sufficiently accurate in practice, because in deducing the molecular weight from the vapour density, relatively large numbers are considered and the little differences do not come into consideration. A greater inaccuracy may arise in the method of introducing the substances into the apparatus because air is apt to enter the vessel. *L. Meyer* (B. **13**, 991), *Piccard* (B. **13**, 1080), *Mahlmann* (B. **18**, 1624), and *V. Meyer* and *Biltz* (B. **21**, 688) have suggested various devices to avoid this source of error. To test the liability to decomposition of the substance at the temperature of the experiment, a small

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* Consult Handwörterbuch der Chemie, Ladenburg, Bd. **3**, 244.

† It is simpler to make the reduction to 760 mm. 0° by comparison with a normal volume (p. 7).

portion of it may be heated in a glass bulb drawn out to a long point (B. **14**, 1466).

Substances boiling above 300° are heated in a lead-bath (B. **11**, 2255). Porcelain vessels are used when the temperature required is so high as to melt glass, and the heating is then carried out in a Perrot's gas oven (B. **12**, 1112). Where air affects the substances in vapour form, the apparatus is filled with pure nitrogen (B. **18**, 2809; **21**, 688). If the substances under investigation attack porcelain, tubes of platinum are substituted for the latter, which are enclosed in glazed porcelain tubes, and then heated in furnaces (B. **12**, 2204; Z. phys. Ch. **1**, 146; B. **21**, 688). This form of apparatus allows of the simultaneous determination of temperature (B. **15**, 141; Z. phys. Ch. **1**, 153).

For modifications in displacement methods of determining the density of gases, consult *V. Meyer* (B. **15**, 137, 1161, 2771); *Langer* and *V. Meyer*, Pyrotechnische Untersuchungen, 1885; *Crafts* (B. **13**, 851; **14**, 356; **16**, 457). For air-baths and regulators see *L. Meyer* (B. **16**, 1087; **17**, 478).

Modifications of the displacement method, adapted for work under reduced pressure, have been proposed by *La Coste* (B. **18**, 2122), *Schall* (B. **22**, 140, with bibliography; B. **27**, R. 604), *Eyckmann* (B. **22**, 2754), *V. Meyer* and *Demuth* (B. **23**, 311); *Richards* (B. **23**, 919, note), *Neuberg* (B. **24**, 729, 2543).

For further methods see *Nilson* and *Pettersson* (B. **17**, 987; **19**, R. 88; J. pr. Ch. **33**, 1); *Biltz* (B. **21**, 2767).

(3) *Determination of the Molecular Weight of Substances when in Solution*

1. **By Means of Osmotic Pressure.**—According to the theory of solutions developed by *van 't Hoff* (Z. phys. Ch. **1**, 481; **3**, 198; B. **27**, 6),* chemical substances, when in dilute solution, behave as though they were in the form of a gas or vapour; so that the laws of *Boyle* and *Gay-Lussac*, and the hypothesis of *Avogadro*, apply also to dilute solutions. We know that the gas particles exert pressure, and it is also true that the particles of compounds, when dissolved, exert a pressure, which is directly expressed or shown by osmotic phenomena, and hence it is termed *osmotic pressure*. This pressure is equal to that which would be exerted by an equal amount of the substance, if it were converted into a gas, and occupied the same volume, at the same temperature, as the solution. Solutions containing molecular quantities of different substances exert the same osmotic pressure. It is, therefore, possible, as in the case of gas pressure, to deduce directly the molecular weight of the substance in solution from its osmotic pressure.

Pfeffer has determined osmotic pressure by means of artificial cells having semi-permeable walls. If suitably modified, this method promises to be of wide applicability (*Ladenburg*, B. 22, 1225).

The *plasmolytic method* of *de Vries* for the determination of osmotic pressure, is based upon the use of living plant-cells, in place of which *Hamburger* employed red blood corpuscles (Z. physik. Ch. **2**, 415; **14**, 424).

The molecular weight is most simply calculated by the general formula for gases: $pv = RT$, in which R represents a constant, and T the absolute temperature, calculated from $-273°$. If this equation is also to include the hypothesis of *Avogadro* (that the molecular weights of gases or dissolved substances occupy the same volume at like temperature and pressure), then molecular quantities of the substances must always be taken into consideration. The constant equals 84000 for gram-molecular weights (2 grams hydrogen, or 31·74 grams oxygen)

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* See Ostwald's Grundriss der allgemeinen Chemie, 2. Aufl. 1890; Lothar Meyer-Rimbach Grundzüge der theoretischen Chemie, 4. Aufl. 1907.

at the temperature 0° (or 273°), and the pressure (gas or osmotic pressure) of 76 cm. of mercury.

$$p \, . \, v = 84000 \, . \, T.^{*}$$

where v represents the volume corresponding to the gram-molecular weight ($v = \frac{M}{a}$, in which a is the weight in grams of 1 c.c. of the gas, or dissolved substance, contained in 1 c.c. of the solution). After substitution the formula reads:

$$p \, . \, 13{\cdot}59 \times \frac{M}{a} = 84000 \; (273 + t),$$

with the four variables p, M, a and t. If three of these be given the fourth can be calculated. Consequently, the molecular weight M is found from the formula—

$$M = \frac{a \, . \, 84000(273 + t)}{p \, . \, 13{\cdot}59} = \frac{a \, . \, 618(273 + t)}{p}.$$

2. **From the Lowering of the Vapour Pressure or the Raising of the Boiling Point.**—The lowering of the vapour pressure of solutions is closely connected with osmotic pressure. Solutions at the same temperature have a lower vapour pressure (f') than the pure solvent (f), and consequently boil at a higher temperature than the latter. The lowering in pressure ($f - f'$) is in proportion to the quantity of the substance dissolved (*Wüllner*), according to the equation $\frac{f - f'}{f} = k \, g$, in which k represents the "relative lowering of the vapour pressure" $\left(\frac{f - f'}{f}\right)$ for 1 per cent. solutions, and g their percentage content.

If the lowering be referred not to equal quantities, but to molecular quantities of the substances dissolved, it is found that equi-molecular solutions (those containing molecular quantities of the different substances in equal amounts in the same solvent) show equal lowering—the molecular vapour pressure lowering is constant:—

$$M . \frac{f - f'}{f} = C.$$

Again, on comparing the relative lowering of vapour pressure in different solvents, it will be found also that they are equal, if equal amounts of the substances are dissolved in molecular quantities of the solvent. In its broadest sense the law would read: The lowering of vapour-pressure is to the vapour-pressure of the solvent (f) as the number of molecules of the dissolved body (n) is to the total number of molecules ($n + N$):—

$$\frac{f - f'}{f} = \frac{n}{n + N}.$$

Substituting $\frac{g}{m}$ and $\frac{G}{M}$ (g and G represent the weight quantities of the substance and the solvent; m and M are their molecular weights), for n and N, the molecular weights, can readily be calculated.

F. M. Raoult (1887) discovered these relationships and put them forward as being empirical. Soon after *van 't Hoff* (Z. phys. Ch. **3**, 115) deduced them theoretically from the osmotic pressure. They are only of value for substances non-volatile as compared with the solvent, or for such as volatilize with difficulty, and show the same abnormalities as are observed with osmotic pressure and depression in the freezing point.

The methods for the determination of vapour pressure are yet too little known and primitive in their nature to be applied in the practical determination of molecular weights (B. **22**, 1084; Z. phys. Ch. **4**, 538). Far more simple and exact is the determination of the rise in the boiling point, which corresponds with this (*Beckmann*, Z. phys. Ch. **4**, 539; **6**, 437; **8**, 223; **15**, 656; B. **27**, R. 727; **28**, R. 432).

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* $R = \frac{pv}{T}$; $p = 1033 = 76 \times 13{\cdot}59$ (sp. gr. of mercury); $v = 22196 = \frac{31{\cdot}74}{0{\cdot}001430}$ (wt. of 1 c.c. of oxygen). $R = \frac{1033 \times 22196}{273}$.

Method of Beckmann.—A tube, *A* (Fig. 4), is employed as the boiling vessel, and is provided with two side tubes t_1 and t_2. The substance under examination is introduced through t_1; a condenser, *N*, is attached to t_2, and a calcium chloride tube may be inserted at *M*. Garnets or fragments of platinum are introduced into the main tube, followed by the solvent, and finally the opening is closed by a differential thermometer (*Beckmann*, Z. physik. Ch. **51**, 329), of which the bulb must be completely covered by the liquid. The boiling tube is surrounded with an air-bath consisting of a mica cylinder, *g*, and two glass-wool plugs, h_1 and h_2. When dealing with liquids of high boiling point the air-bath may be replaced by a vapour-bath made of glass or porcelain, which is charged with the same liquid as that which is employed as the solvent; otherwise the boiling tube may be heated directly on an asbestos netting, *LD*, over a micro-burner. The boiling point of the pure solvent is first read, and then again after a known quantity of the solute has been introduced down the tube *t*. A rise of temperature is observed, and should be taken after each of several successive additions of weighed quantities of the solute.

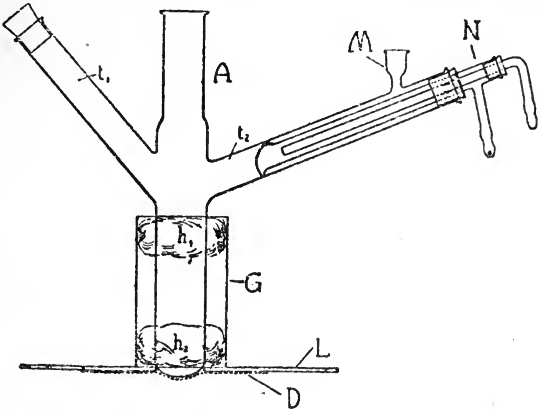

FIG. 4.

A modification of the apparatus has been devised by *Beckmann* (Z. physik. Ch. **44**, 161) based on that of *Sakurai* and *Landsberger* (B. **31**, 458; **36**, 1555). In this form, the temperature of the solution is raised by passing into it the vapour of the solvent, whereby continuous readings can be taken of the boiling point of the solution of a constant weight of solute in an increasing quantity of solvent. *S. Arrhenius* has deduced a formula for the molecular rise in boiling point, which is perfectly analogous to that of *van 't Hoff* for the molecular depression of the freezing point. The molecular rise is expressed by $d = 0{\cdot}02 \cdot \frac{T^2}{w}$, in which T represents the absolute boiling point, and *w* the heat of evaporation of the solvent. Upon dissolving 1 gram-molecule of a substance, *i.e.* if the molecular weight of the body is *m*, then *m* grams of it in 100 grams of solvent, the boiling point will be raised $d°$; upon dissolving *p* grams of the substance in 100 gr. of solvent the rise will be $d_1°$ whence $d_1 = d \cdot \frac{p}{m}$; from which

$$m = p \cdot \frac{d}{d_1}$$

where

p = the weight (in grams) of the substance, dissolved in 100 grams of the solvent,

d = molecular rise in boiling point $\left(= 0{\cdot}02 \cdot \frac{T^2}{w}\right)$,

d_1 = observed rise in boiling point.

The molecular rise of the boiling point in the case of ether is 21·1°, of chloroform 36·6°, and of acetic acid 25·3°.

3. **From the Depression of the Freezing Point.**—The molecular weights of dissolved substances are accurately and readily

deduced from the depression of the freezing points of their solutions. *Blagden* in 1788, and *Rudorff* in 1861, found that the depression of the freezing points of crystallizable solvents, or substances (as water, benzene, and glacial acetic acid) is proportional to the quantity of substance dissolved by them. The later researches of *Coppet* (1871), and especially those of *Raoult* (1882), have established the fact that when molecular quantities of different substances are dissolved in the same amount of a solvent, they show the same depression in their freezing points (*Law of Raoult*). If t represents the depression produced by p grams of a substance dissolved in 100 grams of the solvent, the coefficient of depression $\frac{t}{p}$ will be the depression for 1 gram of substance in 100 grams of the solution.* The *molecular depression* is the product obtained by multiplying the depression coefficient by the molecular weight of the dissolved substances. This is a constant for all substances having the same solvent :—

$$M \cdot \frac{t}{p} = C.$$

Raoult's experiments show the constant to have approximately the following values : for benzene, 49 ; for glacial acetic acid, 39 ; for water, 19. When the constant is known, the molecular weight is calculated as follows :—

$$M = C\frac{p}{t}.$$

A comparison of the constants found for different solvents will disclose the fact that they bear the same ratio to each other as the molecular weights—that consequently the quotient obtained from the molecular depressions and molecular weights is a constant value of about 0·62. It means, expressed differently, that the molecule of any one substance dissolved in 100 molecules of a liquid lowers the point of solidification very nearly 0·62°.

These empirical laws, discovered by *Coppet* and *Raoult*, have been theoretically deduced by *Guldberg* (1870) and *van 't Hoff* (1886) from the diminution of vapour pressure and of osmotic pressure. The constant C is obtained for the various solvents, from the formula $0{\cdot}02\frac{T^2}{w}$, where T indicates the absolute temperature of solidification of the solvent, and w is its latent heat of fusion. In this way *van 't Hoff* calculated the constants for benzene (53), acetic acid (38·8), and water 18·9 (see above).

The laws just described can only be employed in their simple form in the case of indifferent or but slightly chemically active substances.

Salts, strong acids, and bases (all electrolytes) behave unexpectedly in that the depressions of freezing point, the change in osmotic pressure, and the lowering of vapour pressure as found experimentally are all greater than their calculated values ; the electrolytic dissociation theory of *Arrhenius* (Z. phys. Ch. **1**, 577, 631 ; **2**, 491 ; B. **27**, R. 542) accounts for this by the assumption that the electrolytes have separated into their free ions. However, even the indifferent bodies exhibit many abnormalities—generally the very opposite of the ordinary. These seem to be due to the fact that the substances held in solution had not completely broken up into their individual molecules. The

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* *Arrhenius* (Z. phys. Ch. **2**, 493) expresses the content of solutions by the weight in grams of the substances contained in 100 c.c. of the solution.

most accurate results are obtained by operating with very dilute solutions, and by employing glacial acetic acid as solvent. This dissociates solids most readily.

Various forms of apparatus suitable for the above purpose, and methods of working have been proposed by *Auwers* (B. **21**, 711), *Holleman* (B. **21**, 860), *Hentschel* (Z. phys. Ch. **2**, 307), *Beckmann* (Z. phys. Ch. **2**, 638), *Eykmann* (Z. phys. Ch. **2**, 964), *Klobukow* (Z. phys. Ch. **4**, 10), and *Baumann* and *Fromm* (B. **24**, 1431).

Method of Beckmann.—A thick walled test tube, 2–3 cm. in diameter, to which a side tube has been fused (Fig. 5), is partially filled with 10–15 gm. of solvent, weighed to the nearest gram. A platinum stirrer is inserted, which terminates at its upper end in a platinized or enamelled iron ring. The freezing tube is then closed with a stopper carrying a Beckmann thermometer (p. 15). Above the iron ring of the stirrer is fixed a small electromagnet, which is energized by the accumulators *A* at periods determined by the metronome *M*. The stirrer is thus kept continuously in motion, whilst the injurious effect of the atmospheric moisture is avoided. The lower part of the freezing tube is fixed by means of a cork inside a wider tube in order to prevent a too rapid fall of temperature when the apparatus is plunged into a beaker containing a freezing mixture. When the solvent chosen is acetic acid (solidifying about 16°) cold water may be employed; for benzene (solidifying about 5°), ice-water is suitable. The freezing point of the solvent is then determined, by cooling it to 1–2° below its solidifying point and then starting crystallization by stirring, or by the introduction of scraps of platinum foil or by "inoculation" with a crystal of the substance forming the solute. The thermometer then suddenly rises a little, and the freezing point is taken to be that at which the mercury remains constant for a little while. After allowing the mass to thaw, a carefully weighed quantity of the solid to be examined is introduced down the side tube, and allowed to dissolve. The freezing point of the solution is then determined in a similar manner to that just described (B. **28**, R. 412; C. 1910, I. 241; II. 361; Z. phys. Ch. **40**, 192; **44**, 169).

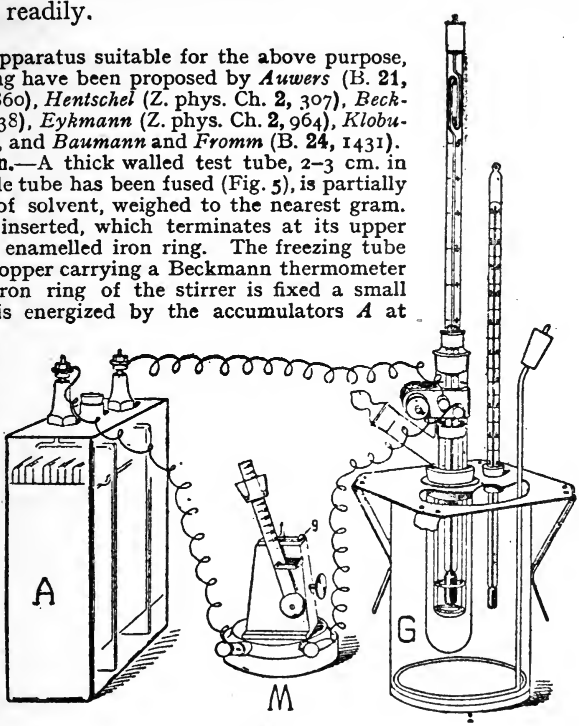


FIG. 5.

Eykmann's Method (A. **273**, 98) requires phenol as the solvent (melting about 38°), whereby considerable simplification is possible. Its molecular depression is greater than that of benzene, and has been calculated theoretically as being 76 (p. 16). Fig. 6 represents the form of apparatus, which consists of a flask with two tubulures, in one of which a thermometer is fixed, and over the other is placed a ground-glass cap.

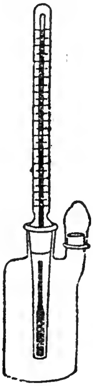


FIG. 6.

The investigations of *Paterno* and others show, contrary to earlier observations, that when benzene is employed as the solvent the carbon derivatives mostly yield normal results; the exceptions being the alcohols, phenols, acids, oximes, and pyrrole (B. **22**, 1430 and Z. phys. Ch. **5**, 94; B. **27**, R. 845; **28**, R. 974).

Naphthalene may also be used for determinations of this kind; *van 't Hoff* gives its depression constant as being about 70 (B. **22**, 2501; **23**, R. 1; **24**, 1431).

Consult B. **28**, 804 for a method of determining molecular weights from the *decrease in solubility*.

For the determination of molecular weight from *molecular solution-volume*, see B. **29**, 1023.

THE CHEMICAL CONSTITUTION OF THE CARBON COMPOUNDS

Early Theories.—The opinion that the cause of chemical affinity resided in electrical forces was first expressed in the commencement of the last century, when the remarkable decompositions of chemical bodies through the agency of the electric current were discovered. It was assumed that the elementary atoms possessed different electrical polarities, and that the elements were arranged in a series according to their electrical behaviour. Chemical union depended on the equalization of different electricities. The *dualistic* idea of the constitution of compounds was a necessary consequence of this hypothesis. According to it, every chemical compound was composed of two groups, electrically different, and these were further made up of two different groups or elements. Thus, salts were viewed as combinations of electro-positive bases (metallic oxides), with electro-negative acids (acid anhydrides), and these, in turn, were held to be binary compounds of oxygen with metals and non-metals. With this as basis there was constructed the *electro-chemical, dualistic theory of Berzelius*, which almost exclusively dominated chemical science in Germany until the beginning of 1860.

The principles predominating in inorganic chemistry were also applied to organic substances. It was thought that in the latter complex groups (radicals) played the same *rôle* as that of the elements in inorganic chemistry. Organic chemistry was defined as the *chemistry of the compound radicals* (*Liebig*, 1832), and led to the *chemical-radical theory*, which flourished in Germany simultaneously with the *electro-chemical* theory. According to this view, the object of organic chemistry was the investigation and isolation of radicals, in the sense of the dualistic idea, as the more intimate components of the organic compounds, and by this means they sought to explain the constitution of the latter. (*Liebig* and *Wöhler*, Ueber das Radical der Benzoësäure, A. **3**, 249; *Bunsen*, Ueber die Kakodylverbindungen, A. **31**, 175; **37**, 1; **42**, 14; **46**, 1.)

In the meantime, about 1830, France contributed facts not in harmony with the electro-chemical, dualistic theory. It had been found that the hydrogen in organic compounds could be replaced (substituted) by chlorine and bromine, without any important change in the character of the compounds. To the electro-negative halogens was ascribed a chemical function similar to electro-positive hydrogen. This showed the electro-chemical hypothesis to be erroneous. The dualistic idea was superseded by a *unitary* theory. Laying aside all the primitive speculations on the nature of chemical affinity, the chemical compounds began to be looked upon as being constituted in accordance with definite fundamental forms—*types*—in which the individual elements could be replaced by others (early type theory of *Dumas*, nucleus theory of *Laurent*). *Dumas*, however, distinguished between *chemical* types and *mechanical* types. He considered substances to have the same *chemical* type, to be of the same species, when they possessed the same fundamental properties, *e.g.* acetic and chloracetic acids. Like *Regnault*, he considered that they were of the same mechanical type, belonged to the same natural family, when they were related in structure but showed a different chemical character, *e.g.* alcohol and acetic acid. At the same time, the dualistic view on the pre-existence of radicals was refuted.

The correct establishment of the ideas of *equivalent*, *atom*, and *molecule* (*Laurent* and *Gerhardt*) was an important consequence of the typical unitary idea of chemical compounds. By means of it a correct foundation was laid for further generalization. The molecule having been accepted as a chemical unit, the study of the grouping of atoms in the molecule became possible, and chemical constitution could again be more closely examined. The investigation of the reactions of double decomposition, whereby single atomic groups (radicals or residues) were preserved and could be exchanged (*Gerhardt*); the important discoveries of the amines or substituted ammonias by *Würtz* (1849), and *Hofmann*

(1849); the epoch-making researches of *Williamson* and *Chancel* (1850), upon the composition of ethers; and the discovery of acid-forming oxides by *Gerhardt* (1851),—led to a "type" explanation of the individual classes of compounds. *Williamson* referred the alcohols and ethers to the water type. *A. W. Hofmann* deduced the substituted ammonias from ammonia. The "type" idea found its culmination in the *type theory of Gerhardt* (1853), which was nothing more than an amalgamation of the early type or substitution theory of *Dumas* and *Laurent* with the radical theory of *Berzelius* and *Liebig*. The molecule was its basis, in which a further grouping of atoms was assumed. The conception of radicals became different; they were no longer regarded as atomic groups that could be isolated and compared with elements, but as molecular residues which remained unaltered in certain reactions.

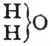
Comparing the carbon compounds with the simplest inorganic derivatives, *Gerhardt* referred them to the following principal fundamental *forms* or *types*:—


$\left.\begin{matrix}H\\H\end{matrix}\right\}$

Hydrogen.


$\left.\begin{matrix}Cl\\H\end{matrix}\right\}$

Hydrogen Chloride.

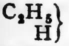

$\left.\begin{matrix}H\\H\end{matrix}\right\}O$

Water.

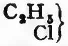

$\left.\begin{matrix}H\\H\\H\end{matrix}\right\}N$

Ammonia.

From these they could be obtained by substituting the compound radicals for hydrogen atoms. All compounds that could be viewed as consisting of two directly combined groups were referred to the hydrogen and hydrogen chloride types, *e.g.*:


$\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}$

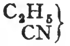
Ethyl Hydride.


$\left.\begin{matrix}C_2H_5\\Cl\end{matrix}\right\}$

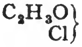
Ethyl Chloride.


$\left.\begin{matrix}CN\\H\end{matrix}\right\}$

Cyanogen Hydride.


$\left.\begin{matrix}C_2H_5\\CN\end{matrix}\right\}$

Ethyl Cyanide.


$\left.\begin{matrix}C_2H_3O\\Cl\end{matrix}\right\}$

Acetyl Chloride.

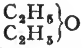
It was customary to refer all those bodies derivable from water by the replacement of hydrogen, to the water type:


$\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O$

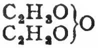
Alcohol.


$\left.\begin{matrix}C_2H_3O\\H\end{matrix}\right\}O,$

Acetic Acid.


$\left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O$

Ethyl Ether.


$\left.\begin{matrix}C_2H_3O\\C_2H_3O\end{matrix}\right\}O$

Acetic Anhydride.

Associated types were included with the principal types. Thus, with the fundamental type $\left.\begin{matrix}Cl\\H\end{matrix}\right\}$ were arranged, as subordinates, the types $\left.\begin{matrix}Br\\H\end{matrix}\right\}$ $\left.\begin{matrix}I\\H\end{matrix}\right\}$; with the water type $\left.\begin{matrix}H\\H\end{matrix}\right\}O$ that of $\left.\begin{matrix}H\\H\end{matrix}\right\}S$, etc.

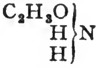
All derivatives of ammonia were referred to the ammonia type:


$\left.\begin{matrix}CH_3\\H\\H\end{matrix}\right\}N$

Methyl-amine.


$\left.\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right\}N$

Trimethyl-amine.


$\left.\begin{matrix}C_2H_3O\\H\\H\end{matrix}\right\}N$

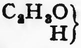
Acetamide.


$\left.\begin{matrix}CO\\H\end{matrix}\right\}N$

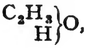
Cyanic Acid.

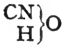
The types of *Gerhardt* were chemical types, as he himself expresses it: "Mes types sont des types de double décomposition." It is thus understood that he included the type $\left.\begin{matrix}Cl\\H\end{matrix}\right\}$ with that of $\left.\begin{matrix}H\\H\end{matrix}\right\}$.

These types no longer possessed their early restricted meaning. Sometimes a compound was referred to different types, according to the transpositions the formula was intended to express. Thus aldehyde was referred to the hydrogen or water type; cyanic acid to the water or ammonia type:

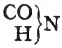

$\left.\begin{matrix}C_2H_3O\\H\end{matrix}\right\}$

and


$\left.\begin{matrix}C_2H_3\\H\end{matrix}\right\}O,$


$\left.\begin{matrix}CN\\H\end{matrix}\right\}O$

and


$\left.\begin{matrix}CO\\H\end{matrix}\right\}N$

The development of the idea of polyatomic radicals, the knowledge that the hydrogen of carbon radicals could be replaced by the groups OH and NH_2, etc., contributed to the further establishment of *multiple* and *mixed types* (*Williamson*, *Odling*, *Kekulé*):

Compound Types :

$$\left.\begin{matrix}ClH\\ClH\end{matrix}\right\} \qquad \left.\begin{matrix}H_2\\H_2\end{matrix}\right\}O_2 \qquad \left.\begin{matrix}H_2\\H_2\\H_2\end{matrix}\right\}N_2$$

e.g. :—

$$\left.\begin{matrix}Cl\\C_2H_4''\\Cl\end{matrix}\right\} \qquad \begin{matrix}\left.\begin{matrix}H\\C_2H_4''\end{matrix}\right\}O\\\left.\begin{matrix}\\H\end{matrix}\right\}O\end{matrix} \qquad \begin{matrix}\left.\begin{matrix}H_2\\CO''\end{matrix}\right\}N\\\left.\begin{matrix}\\H_2\end{matrix}\right\}N\end{matrix}$$

Ethylene Chloride. Ethylene Glycol. Carbamide.

Mixed Types :

$$\left.\begin{matrix}Cl\\H\end{matrix}\right\} \left\{\begin{matrix}\\\\\end{matrix}\right. \left.\begin{matrix}H_2\\H_2\end{matrix}\right\}O_2 \qquad \left.\begin{matrix}H\\H\end{matrix}\right\}N \left\{\begin{matrix}\\\\\end{matrix}\right. \left.\begin{matrix}H\\H\end{matrix}\right\}O$$

$$\begin{matrix}\left.\begin{matrix}Cl\\C_3H_5'''\end{matrix}\right\}\\\left.\begin{matrix}\\H_2\end{matrix}\right\}O_2\end{matrix} \qquad \begin{matrix}\left.\begin{matrix}H_2\\C_2O_2''\end{matrix}\right\}N\\\left.\begin{matrix}\\H\end{matrix}\right\}O\end{matrix} \qquad \begin{matrix}\left.\begin{matrix}H_2\\C_2H_2O''\end{matrix}\right\}N\\\left.\begin{matrix}\\H\end{matrix}\right\}O\end{matrix}$$

Chlorhydrin. Oxamic Acid. Amido-acetic Acid.

The presentation of these multiple and mixed types depended on the polyatomic radicals of two or more *type-molecules*, if one may so name them, becoming united into one whole—a molecule. Upon comparing these typical with the structural formulæ employed at present, we observe that the first constitute the transitional state from the empirical, unitary formulæ to those of the present day. The latter aim to express the kind of *grouping* of the atoms in the molecule.

The next step was the expansion of the *Gerhardt* type to the—

Marsh-gas type $\left.\begin{matrix}H\\H\\H\\H\end{matrix}\right\}C$ by *Kekulé*, 1856 (A. **101**, 204).

Recent Views.—A year later *Kekulé* (1857) in a communication, "Ueber die sog. gepaarten Verbindungen und die Theorie der mehratomigen Radicale" (A. **104**, 129), indicated the idea of types by the assumption of a peculiar function of the atoms—their atomicity or basicity (valence). This he supposed to be the cause of the types of *Gerhardt*.

As early as 1852 *Frankland* had enunciated similar views in regard to the elements of the nitrogen group (A. **85**, 329; **101**, 257; *Frankland*, Experimental Reseaches in Pure, Applied, and Physical Chemistry, London, 1871, p. 147). *Kolbe* concurred with these ideas (compare his derivation of the organic compounds from the radical carbonyl C_2 and carbon dioxide C_2O_4—*Kolbe's* Lehrbuch der organischen Chemie, 1858, Bd. I. p. 567). The reason that they did not exert greater influence upon the development of theoretical chemistry is mainly due to the fact that the notions of the relations of equivalent weight and atomic weight were not clearly defined by either of these two investigators.

In his assumptions *Kekulé* rather returned to *Dumas'* mechanical types than to the double decomposition types of *Gerhardt*. The distinction between the type $\left.\begin{matrix}H\\H\end{matrix}\right\}$ and $\left.\begin{matrix}Cl\\H\end{matrix}\right\}$ as drawn by *Gerhardt* did not exist for *Kekulé*. The latter, in 1858, said, "It is necessary in explaining the properties of chemical compounds to go back to the elements which compose these compounds." He continues: "I do not regard it as the chief aim of our time to detect atomic groups which, owing to certain properties, may be considered radicals and thus to include the compounds under certain types, which in this way have scarcely any other significance than that of type or example formula. I am rather of the opinion that the generalization should be extended to the constitution of the radicals themselves, to the determination of the relation of the elements among themselves, and thus to deduce from the nature of the elements both the nature of the radicals and that of their compounds" (A. **106**, 136).

The recognition of the quadrivalence of the carbon atoms and the power they possessed of combining with each other, accounted for the existence and the combining value of radicals; also, for their constitution (*Kekulé*, *l.c.*, and *Couper*, A. ch. phys. [3] **53**, 469). The type theory, consequently, is not, as sometimes declared, laid aside as erroneous; it has only found generalization and amplification in a broader principle—the extension of the valence theory of *Kekulé* and *Couper* to the derivatives of carbon.

Whilst formerly it was the custom to consider in addition to *empirical* formulæ, representing merely an atomic composition of the molecule, also *rational* formulæ (*Berzelius*), which in reality were nothing more than reaction formulæ adopted to explain to a certain degree the chemical behaviour of derivatives of carbon, *Kekulé* now spoke of the *manner of the union of the atoms in the molecule*, by knowledge of which the constitution of the carbon compounds may be determined (*constitutional formulæ*). *Lothar Meyer* next introduced the phrase "*linking of the carbon atoms.*" The expression *structure* (*structural formulæ*) originated with *Butlerow*.

An application of the valency theory, which has been remarkably fruitful, is the *Kekulé benzene theory*. Here for the first time there was assumed to be present in a carbon compound a closed carbon-chain, a ring consisting of six carbon atoms. The rather singular stability of the aromatic bodies is due to the presence of this "*benzene ring.*" *Körner* applied these views to pyridine and deduced the *pyridine ring*; and in recent years numerous other ring-systems have been suggested and substantiated.

Theory of Chemical Structure of Carbon Compounds. Theory of Atomic Linking, or the Structural Theory.

Constitutional or structural formulæ are based upon the following principles, which have been deduced from experiment and repeatedly confirmed:—

1. *The carbon atom is quadrivalent.* The position of carbon in the periodic system gives expression to this fact. One carbon atom can combine at the most with four similar or dissimilar univalent atoms or atomic groups:

CH_4	CF_4	CCl_4
Methane.	Carbon Tetrafluoride.	Carbon Tetrachloride.

CH_3Cl	CH_3NH_2	CH_2Cl_2	$CHCl_3$
Methyl Chloride.	Methylamine.	Dichloromethane.	Chloroform.

In a few compounds, such as carbon monoxide CO, the isonitriles or carbylamines $R'-N=C$ (A. **270**, 267); and fulminic acid $HO-N=C$ (A. **280**, 303) carbon behaves as a bivalent element.

2. *The four units of affinity of carbon are equal, i.e.* no differences can be discovered in them when they form compounds. If one of the four hydrogen atoms in the simplest hydrocarbon, CH_4, be replaced by a univalent atom or univalent atomic group, each mono-substitution product will appear in but one modification. The four hydrogen atoms are similarly combined, consequently it is immaterial which of them is replaced.

CH_3Cl	CH_3OH	CH_3NH_2
Chloromethane.	Methyl Alcohol.	Methylamine.

are known in but one modification each (p. 29).

3. *The carbon atoms can unite with each other.* When two carbon atoms combine the union can occur in three ways:

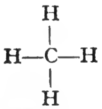
(*a*) The two carbon atoms unite with a single valence each, leaving the atomic group, $\equiv C-C\equiv$, with six free valences.

(*b*) The two carbon atoms unite with two valences each, constituting an atomic group, $=C=C=$, with four free valences.

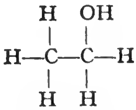
(*c*) Two carbon atoms are united by three valences. The residual group $-C\equiv C-$ has but two uncombined valences.

In the first case the union of the two carbon atoms is *single*, in the second case *double*, and in the third case *triple*. Carbon atoms can combine with themselves to a greater degree than the atoms of any other elements. This gives rise to carbon *nuclei*, and carbon *skeletons*, which form either *open* or *closed chains* or *rings*. The uncombined valences of the carbon nuclei can saturate or take up atoms of other elements or other atomic groups. This explains the existence of the innumerable carbon compounds.

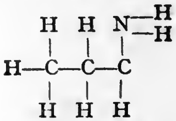
This mutual union is indicated, according to the recommendation of *Couper*, by lines. These formulæ represent the internal construction of the compounds, and are known as *structural formulæ*:



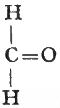
Methane.



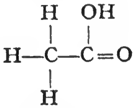
Ethyl Alcohol.



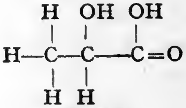
Propylamine.



Formaldehyde.



Acetic Acid.



Lactic Acid.

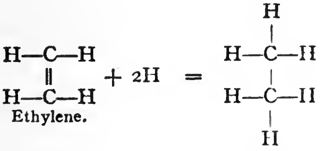
Such structural formulæ have been deduced, by the help of the valency theory, from reactions which result in the building up and the breaking down of carbon compounds. They express clearly the relations between the bonds, which, in the main, determine the behaviour of the substance. Those atoms within the molecule which are bound most directly to each other exercise the greatest influence on one another. But it must not be supposed that atoms, unconnected directly by bonds, exert no mutual influence; such structural formulæ give no information of their relative distances apart in space. In the study of reactions where halogen atoms are substituted for hydrogen in the molecule, it is immediately apparent that such replacement takes place with varying facility. This is specially obvious in the case of the aromatic substances (*see* Volume II). Further, the carboxyl group reacts with different degrees of acidity varying with the individual acid. Reactions, in which the loss of some atoms causes a single bond to become a multiple one, or the formation of a ring complex, and where intra-molecular atomic migration (see p. 36) takes place, obviously depend on the mutual influence of atoms unconnected directly by bonds, as shown in the structural formulæ.

Kekulé's valency theory explains clearly the function of the *main* bonds in our structural formulæ, but does not deal with the *subsidiary* action of the various atoms on one another in the molecule. And yet one cannot go so far as to say that in each atomic constellation which constitutes a molecule, every atom exerts a chemical influence on every other. But so much can be asserted, that each atom contained in the molecule of a chemical compound is bound to each other atom in that molecule. To illustrate such attractions diagrammatically, it would be necessary to draw a network of interatomic bonds in every atomic formula. The greater or lesser strength of the bond could be indicated by a thicker or finer line. If such a diagram were examined at a certain distance, only the thick lines—Bonds of the First Order—would be seen clearly, *i.e.* practically the same in appearance as the structural formula ordinarily represented.

In many cases it can be deduced from the behaviour of the substance that the Bonds of the Second Order exert an influence of negligible strength.

An external sign of the presence of such subsidiary valency—bonds of appreciable influence—is found in the absence of such chemical reactions as might be expected to take place by analogy with others. Another exists in the relative ease with which a group of atoms can be split off, which indicates the pre-existence in the original molecule of such a group held together by these second-order bonds.

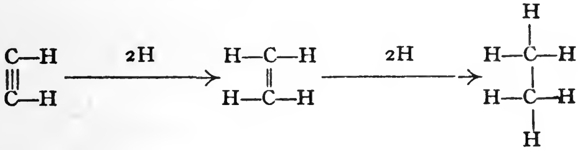
Saturated and Unsaturated Compounds.—*Saturated* carbon compounds are those in which only singly bound carbon atoms occur. They cannot be united by more valences unless the carbon chain is broken up. *Unsaturated* compounds are those in which doubly or triply bound carbon atoms exist. As a single union is sufficient to link carbon atoms together, a pair of carbon atoms with double union can take up two additional valence units, if one of the double bonds becomes broken, for this purpose, leaving the other to avoid destruction of the chain, *e.g.*:



$$H_2C{=}CH_2 + 2H = H_3C{-}CH_3$$

Ethylene. Ethane.

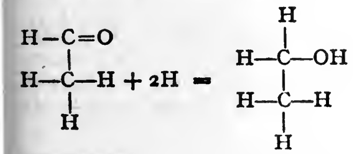
Two carbon atoms, trebly linked, can take up four valences. The dissolution of the triple union may proceed step by step, whereby it may first be changed to a double linkage and then to a simple union:



$$HC{\equiv}CH \xrightarrow{2H} H_2C{=}CH_2 \xrightarrow{2H} H_3C{-}CH_3$$

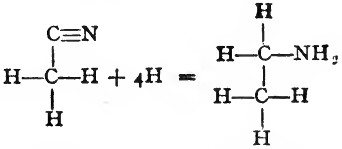
The unsaturated compounds, by the breaking down of their double and triple unions and the addition of two or four univalent atoms, pass into saturated compounds.

This same behaviour is observed with many other compounds containing carbon and oxygen, doubly combined, $=C=O$ (aldehydes and ketones) or double and triple union of carbon and nitrogen, $=C=N-C\equiv N$ (acid nitriles, imides, oximes). They are in the same sense unsaturated; by the breaking down of their double or triple union they change to saturated compounds in which the polyvalent atoms are linked by a single bond to each other:



$$H{-}C{=}O{-}CH_3 + 2H = H{-}CH(OH){-}CH_3$$

Acetaldehyde. Ethyl Alcohol.



$$N{\equiv}C{-}CH_3 + 4H = H_2C(NH_2){-}CH_3$$

Acetonitrile. Ethylamine.

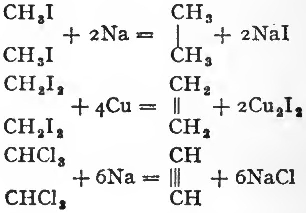
A second class of unsaturated carbon compounds exists, where the carbon atom itself and alone must be looked on as being unsaturated. (A. **298**, 202.) For example:

$=C=O$ Carbon Monoxide.	$=C=N.C_2H_5$ Ethyl Carbylamine and homologues.	$=C=N.OH$ Fulminic Acid.

Radicals, Residues, Groups.—The assumption of the existence of radicals, capable of existing alone and playing a special *rôle* in molecules, has long been abandoned (B. **35**, 1196). The structural formulæ assign no especially favourable position to one atom over another in the molecule. Radicals are atomic groups, chiefly those containing carbon, which in many reactions remain unaltered and pass from one compound into another without change. In this category must also be included the uni-, di-, tri-, and polyvalent atomic complexes, which remain when atoms or atomic groups are imagined to be removed from saturated bodies. By such gradual abstraction of hydrogen, methane yields the following radicals, having different valences:—

CH_4	$—CH_3$	$=CH_2$	$\equiv CH$
Methane, saturated.	Methyl, univalent radical.	Methylene, divalent radical.	Methenyl or Methine, trivalent radical.

If such radicals are isolated from existing compounds, *e.g.* the halogen derivatives, then two of them unite to form a molecule:

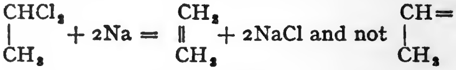


$$\begin{array}{l}CH_3I\\CH_3I\end{array} + 2Na = \begin{array}{c}CH_3\\|\\CH_3\end{array} + 2NaI$$

$$\begin{array}{l}CH_2I_2\\CH_2I_2\end{array} + 4Cu = \begin{array}{c}CH_2\\\|\\CH_2\end{array} + 2Cu_2I_2$$

$$\begin{array}{l}CHCl_3\\CHCl_3\end{array} + 6Na = \begin{array}{c}CH\\|||\\CH\end{array} + 6NaCl$$

Or, an atomic rearrangement may occur with the production of a molecule of the same number of carbon atoms:



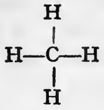
$$\begin{array}{l}CHCl_2\\|\\CH_3\end{array} + 2Na = \begin{array}{l}CH_2\\\|\\CH_2\end{array} + 2NaCl \text{ and not } \begin{array}{l}CH=\\|\\CH_3\end{array}$$

The expressions *residue* and *group* are similar to *radical.* They are chiefly applied to inorganic radicals, *e.g.*:

$—OH$	water residue or Hydroxyl group,
$—SH$	hydrogen sulphide residue or Hydrosulphide group,
$—NH_2$	ammonia residue or Amido group,
$=NH$	Imido group,
$—NO_2$	Nitro group,
$—NO$	Nitroso group.

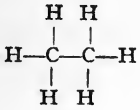
Homologous and Isologous Series.—*Schiel*, in 1842 (A. **43**, 107; **110**, 141), directed attention to the phenomenon of homology, giving as evidence the alcohol radicals, and was followed shortly after by *Dumas*, who observed it in the fatty acids. *Gerhardt* introduced the terms *homologous* and *isologous series*, and showed the *rôle* these series played in the classification of the carbon derivatives. It was the theory of atomic linking that first disclosed the cause of homology.

The different kinds of linkages between the carbon atoms shows itself most plainly among the hydrocarbons. By removing one atom of hydrogen from the simplest hydrocarbon, *methane*, CH_4, the remaining univalent group, CH_3, can combine with another, yielding $CH_3—CH_3$, or C_2H_6, *ethane* or dimethyl. Here, again, a hydrogen atom may be replaced by the group CH_3, resulting in the compound $CH_3—CH_2—CH_3$, *propane*. The structure of these derivatives may be more clearly represented graphically:



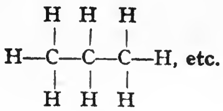
$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

CH_4



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

C_2H_6



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & H, \text{ etc.} \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

C_3H_8

By continuing this chain-like union of the carbon atoms, there arises an entire series of hydrocarbons:

$CH_3—CH_2—CH_2—CH_3$ C_4H_{10} $CH_3—CH_2—CH_2—CH_2—CH_3$, etc. C_5H_{12}

Such a series of bodies of similar chemical structure and corresponding in chemical characters is known as a *homologous series*.

The composition of such an homologous series can be expressed by a general *empirical* or *rational* formula. The series formula for the marsh gas or methane hydrocarbons is C_nH_{2n+2}.

Each member differs from the one immediately preceding and the one following by CH_2. The phenomenon of homology is therefore due to the linking power of the quadrivalent carbon atoms.

On the configuration of the carbon chain, see C. 1900, II. 28, 664, 1256, and Volume II., Cycloparaffins.

In addition to the homologous series of the saturated marsh-gas type, there are a large number of other such series, of which the simplest are those of the monohydroxy-alcohols, the aldehydes and monocarboxylic acids.

	$C_nH_{2n+2}O$		$C_nH_{2n}O$		$C_nH_{2n}O_2$
CH_4O	Methyl Alcohol	CH_2O	Formaldehyde	CH_2O_2	Formic Acid
C_2H_6O	Ethyl Alcohol	C_2H_4O	Acetaldehyde	$C_2H_4O_2$	Acetic Acid
C_3H_8O	Propyl Alcohol	C_3H_6O	Propionaldehyde	$C_3H_6O_2$	Propionic Acid
$C_4H_{10}O$	Butyl Alcohol	C_4H_8O	Butyraldehyde	$C_4H_8O_2$	Butyric Acid
	etc.		etc.		etc.

Carbon compounds, chemically similar, but differing from each other in composition by a difference other than nCH_2, *e.g.* the saturated and unsaturated hydrocarbons, form *isologous* series, according to *Gerhardt*:

$$C_2H_6 \ldots\ldots C_2H_4 \ldots\ldots C_2H_2$$
$$C_3H_8 \ldots\ldots C_3H_6 \ldots\ldots C_3H_4$$

Isomerism; Polymerism; Metamerism; Chain or Nucleus Isomerism; Position or Place Isomerism.—The view once prevailed that bodies of different properties must necessarily possess a different composition. The first hydrocarbons showing that this opinion was erroneous were discovered in 1820.

Liebig, in 1823, demonstrated that silver cyanate and fulminate were identical. In 1828 *Wöhler* changed ammonium cyanate to urea, and in 1830 *Berzelius* established the similarity of tartaric acid and racemic acid.

Berzelius, in 1830, designated as *isomers* (ἰσομερής, composed of similar parts) bodies of similar composition but different in properties. A year later he distinguished two kinds of isomerism, viz.: isomerism of bodies of different molecular mass—*polymerism*; and bodies of like molecular mass—*metamerism*.

Numerous isomeric carbon derivatives were discovered in rapid succession; hence, an answer to the question as to what causes isomeric phenomena acquired importance for the development of organic chemistry. The deeper insight into the structure of carbon compounds, which was gradually attained, gave rise in consequence to a further division of metameric phenomena.

The expression *metamerism* was employed to designate that kind of isomerism which is due to the homology of radicals held in combination by atoms of higher valence. If the homologous radicals are joined by polyvalent elements, then those compounds are metameric, in which the sum of the elements contained in the radicals is the same (H may be viewed as the simplest radical):

$$\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O \quad \text{is metameric with} \quad \left.\begin{matrix}CH_3\\CH_3\end{matrix}\right\}O$$

Ethyl Alcohol. Methyl Ether.

$$\left.\begin{matrix}C_3H_7\\H\end{matrix}\right\}O \quad \text{is metameric with} \quad \left.\begin{matrix}C_2H_5\\CH_3\end{matrix}\right\}O$$

Propyl Alcohol. Ethyl-Methyl Ether.

$$\left.\begin{matrix}C_2H_5\\H\\H\end{matrix}\right\}N \quad \text{is metameric with} \quad \left.\begin{matrix}CH_3\\CH_3\\H\end{matrix}\right\}N$$

Ethylamine. Dimethylamine.

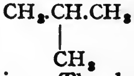
$$\left.\begin{matrix}C_3H_7\\H\\H\end{matrix}\right\}N \quad \text{is metameric with} \quad \left.\begin{matrix}C_2H_5\\CH_3\\H\end{matrix}\right\}N \quad \text{and} \quad \left.\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right\}N$$

Propylamine. Ethyl Methyl-amine. Trimethyl-amine.

The constitution of the radicals in this division was disregarded, the type formulæ were sufficiently explanatory. We have recognized the power of the quadrivalent carbon atoms to unite in a chain-like manner as the cause of homology, and to this cause may be attributed other phenomena of isomerism, which are not properly included under metamerism.

In deducing the formulæ of the five simplest hydrocarbons of the homologous series C_nH_{2n+2}, the formula for ethane, $CH_3.CH_3$, was developed from that of methane, CH_4, and that of propane $CH_3.CH_2.CH_3$ from the formula of ethane C_2H_6. In the case of propane *intermediate* and *terminal* carbon atoms are distinguished. The former are attached on either side to two other carbon atoms, still possessing two valency units which are saturated by two hydrogen atoms. The terminal carbon atoms of the chain are linked to three hydrogen atoms.

With the next member of the series we observe a difference. Above (p. 24), the fact that a hydrogen of the terminal methyl group of propane was replaced by methyl was the only condition considered. This led to the formula $CH_3.CH_2.CH_2.CH_3$. However, the CH_3-group might replace a hydrogen atom of the intermediate CH_2-group, and then the result would be the formula



$$\begin{matrix}CH_3.\underset{|}{C}H.CH_3\\ CH_3\end{matrix}$$

. In this hydrocarbon there is a *branched* carbon chain. The hydrocarbon with a continuous chain is termed *normal butane;* its isomer is *isobutane, i.e.* isomeric *butane.*

Theoretically, by a similar deduction, the two butanes

$CH_3—CH_2—CH_2—CH_3$
Normal Butane.

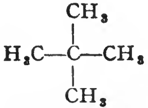
$CH_3CH(CH_3)_2$
Isobutane.

yield three isomeric pentanes which are actually known.

$CH_3.CH_2.CH_2.CH_2.CH_3$
Normal Pentane.

$CH_3.\underset{\underset{\displaystyle CH_3}{|}}{CH}.CH_2.CH_3$

Isopentane.



$H_3C—\overset{\displaystyle CH_3}{\overset{|}{\underset{\underset{\displaystyle CH_3}{|}}{C}}}—CH_3$

Pseudopentane
Tetramethyl Methane.

The number of possible isomers increases rapidly with the increase in carbon atoms (B. **27**, R. 725; **33**, 2131).

The origin of isomerism in the homologous paraffins, as in so many other cases, is the different constitution of the carbon chain. The isomerism caused by a difference in linking, by the different structure of the carbon nucleus or the carbon chain, is termed *nucleus* or *chain isomerism.*

The investigation of the substitution products of the paraffin hydrocarbons brings to light another kind of isomerism. The principle of similarity of the four valences of a carbon atom (p. 21) renders logical and possible but one monochloro-substitution product of methane and ethane. The same consideration which heretofore recognized the possibility of two methyl substitution products of propane (the two butanes possible by theory) leads to the possibility of two monochloropropanes, dependent upon whether the chlorine atom has replaced the hydrogen of a terminal or intermediate carbon atom:

$CH_3.CH_2.CH_2Cl$
Normal Propyl Chloride.

$CH_3.CHCl.CH_3$
Isopropyl Chloride.

If two hydrogen atoms of one of the carbon atoms of propane be replaced by an oxygen atom, the following case of isomerism arises:

$CH_3.CH_2.CHO$
Propyl Aldehyde.

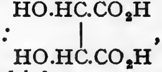
$CH_3.CO.CH_3$
Acetone.

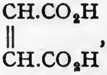
In the case of the two known chloropropanes, and also in the case of propyl aldehyde and acetone, the cause of the isomerism is not due to difference in constitution of the carbon chain, but to the different *position* of the chlorine atoms with reference to the oxygen atoms of the same carbon chain. Isomerism, induced by the different arrangement or position of the substituting elements in the same carbon chain, is designated isomerism of *place* or *position.*

The intimate relationship of the two varieties of isomerism is apparent from the derivation of the ideas of nucleus or chain isomerism and *place* or *position* isomerism.

Recent Views on the Structural Theory.—The theory of atomic linking not only revealed an insight into the causes of the innumerable isomeric phenomena, but predicted unknown instances and determined their number in a very definite manner. In many cases isomeric modifications, possible by theory, were discovered at a later period. For certain isomers, however, at first few in number, the structural formulas deduced from their synthetic and analytical reactions were insufficient, inasmuch as different compounds were known, to which the same structural formula could be given. The greatest similarity in reactions indicative of the structure was combined with complete difference in physical properties of the compounds belonging in this class. The tendency at first was to designate such bodies *physical isomers,* meaning thereby an aggregation of varying complexes of chemically similar molecules.

The following groups of such isomers have been well investigated:

1. The *four symmetrical dihydroxysuccinic acids:*  $\begin{array}{c}\text{HO.HC.CO}_2\text{H}\\ |\\ \text{HO.HC.CO}_2\text{H}\end{array}$, the ordinary or dextro-tartaric acid, and racemic acid, which were proved to be isomeric in 1830 by *Berzelius* (see p. 25), and lævo-tartaric and the inactive or meso-tartaric acids which were added later, through *Pasteur's* classic researches.

2. The *two symmetrical ethylene-dicarboxylic acids:*  $\begin{array}{c}\text{CH.CO}_2\text{H}\\ \|\\ \text{CH.CO}_2\text{H}\end{array}$, fumaric and maleïc acid.

3. The *three a-hydroxypropionic acids:* $CH_3.CH(OH).CO_2H$—inactive lactic acid of fermentation, sarcolactic acid, and lævo-lactic acid, which was added later.

Substances are included among these compounds, which when liquefied, either by fusion or solution, rotate the plane of polarization either to the right or left. The direction of deviation is indicated by prefixing "dextro" or "lævo" to the name of the bodies thus acting. Such carbon compounds are "optically active" (p. 54), in contradistinction to the other almost innumerable derivatives which exert no influence on polarized light and are "optically inactive" or "inactive."

A direct synthesis of optically active carbon compounds has not yet been achieved (*see* asymmetric synthesis, p. 55), although optically inactive bodies have been synthesized. *Pasteur* discovered methods by means of which the latter can be resolved into their components, which rotate the plane of polarization to an equal degree but in opposite directions. Upon splitting sodium-ammonium racemate into sodium-ammonium lævo- and dextro-tartrates, *Pasteur* observed that the crystals of these salts showed hemihedrism; that they were as an object to its mirror-image; and that equally long columns of equally concentrated solutions of these salts, at the same temperature, deviated the plane of polarized light to an equal degree in opposite directions.

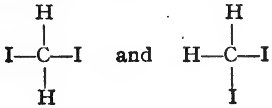
In 1860 *Pasteur* expressed himself as follows upon the cause of these phenomena—upon molecular asymmetry: "Are the atoms of the dextro-acid grouped in the form of a right-handed spiral, or *are they arranged at the angles of an irregular tetrahedron,* or are they distributed according to some other asymmetric arrangement? We know not. Undoubtedly, however, we have to do with an asymmetric arrangement, the images of which cannot mutually cover each other. It is not less certain that the atoms of the lævo-acid are arranged in opposite order." In 1873 *J. Wislicenus* added the following comment to the evidence of similar structure in the optically inactive lactic acid of fermentation and the optically active sarcolactic acid: "Facts compel us to explain the difference of isomeric molecules of like structural formula by a difference in arrangement of the atoms in space." How the *space configuration* of the molecules of carbon compounds was to be represented was answered almost simultaneously and independently of each other by *van 't Hoff* and *Le Bel* (1874) (B. **26**, R. 36), by the introduction of the hypothesis of the asymmetric carbon atom. This hypothesis is the basis of the chemistry of *space* or *stereo-chemistry* of the carbon atom.

The hypothesis of an asymmetric carbon atom * is designed to explain optical activity and the isomerism of optically active carbon compounds.

Whilst the theory of atomic linkage abstains from any representation of the spacial arrangement of the atoms in a molecule, experience gathered from the investigation of simple carbon compounds shows that definite spacial relations do not harmonize with actual facts. Assuming that the four valences of a carbon atom act in a plane and in perpendicular directions upon each other, the following possible isomers for methane are evident :—

No isomers of the types CH_3R^1 and $CH(R^1)_3$
Two ,, ,, ,, $CH_2(R^1)_2$, $CH_2R^1R^2$, $CHR^2(R^1)_2$,
Three ,, ,, ,, $CHR^1R^2R^3$.

Methylene iodide, for example, should appear in two isomeric modifications



$$\begin{array}{c}H\\|\\I-C-I\\|\\H\end{array} \quad \text{and} \quad \begin{array}{c}H\\|\\H-C-I\\|\\I\end{array}$$

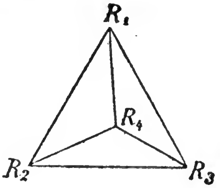
However, two isomers of a single disubstitution product of methane have never been found ; consequently, it is very improbable that the four affinities of a carbon atom are disposed in the manner indicated above. The carbon atom models of *Kekulé* represent the carbon atom as a black sphere and the quadrivalence of it by four needles of equal length and firmly attached to the sphere, which *Baeyer* has called axes. These needles are not perpendicular to each other, nor do they lie in the same plane, but are so arranged that planes placed about their terminals produce a regular tetrahedron (Z. f. Ch. (1867) N. F. **3**, 216). *Van 't Hoff's* generalizations are based upon this model, about which fundamental considerations will be more fully developed in the following pages.

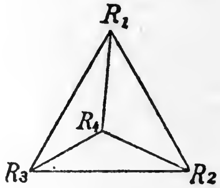
On the assumption that the affinities of a carbon atom are directed towards the summits of a regular tetrahedron, in the centre of which is the carbon atom, there would be no imaginable isomers coinciding

* *Pasteur :* Recherches sur la dissymétrie moléculaires des produits organiques naturels. Leçons de chimie professées en 1860. Paris, 1861. Vgl. Ostwald's Klassiker der exacten Wissenschaften, Nr. 28 : Ueber die Asymmetrie bei natürlich vorkommenden organischen Verbindungen, von *Pasteur*. Uebersetzt und herausgegeben von *M.* und *A. Ladenburg*. *J. H. van 't Hoff :* Dix années dans l'histoire d'une théorie, 1887. *K. Auwers :* Die Entwickelung der Stereochemie, Heidelberg, 1890. *A. Hantzsch :* Grundriss der Stereochemie, Breslau, 1893. *C. A. Bischoff :* Handbuch der Stereochemie, 1893, together with, Materialien der Stereochemie, 1904. *Werner :* Lehrbuch der Stereochemie, 1904.

with $CH_2(R^1)_2$, $CH_2R^1R^2$, $CHR^2(R^1)_2$, but a case such as $CHR^1R^2R^3$ or the more general $CR^1R^2R^3R^4$—an isomeric phenomenon of peculiar nature—might be predicted. A carbon atom of this description—one that is connected with four different univalent atoms or atomic groups —*van 't Hoff* has designated an *asymmetric carbon atom*, proposing to represent it by an italic *C*. It is often indicated by a small star.

If a compound contains an asymmetric carbon atom we can conceive of its existence in two isomeric modifications, the one being an image of the other:



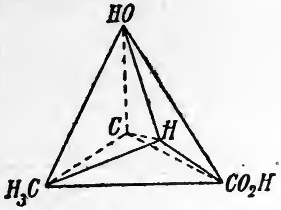


These spacial arrangements are more fully understood by the aid of the models suggested by *Kekulé*, *van 't Hoff*, and others, than by their projection upon the flat surface of paper. *Van 't Hoff* introduced tetrahedron models in which the solid angles were coloured; this was to represent and indicate different radicals. They lack this advantage, possessed by the *Kekulé* model, that the carbon atom has entirely disappeared from the model. It must be imagined as being in the centre of the tetrahedron, and in projections of these models (see above) the radicals are united to each other by lines, the latter, however, not in any sense representing a chemical union.

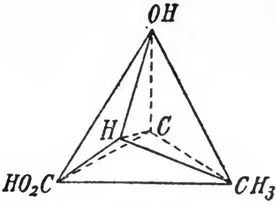
In the left tetrahedron the successive series $R^1R^2R^3$ proceeds in a direction directly opposite to that of the hand of a watch, whilst in the right tetrahedron the course coincides with that of the hand. The two figures cannot, by rotation, be by any means brought into the same position,—that is, in a position to cover each other completely,— any more than the left hand can be made to cover the right, or a picture its image or reflection.

The Isomerism of Optically Active Carbon Compounds.—The cause of optical activity, in the opinion of *van 't Hoff* and of *Le Bel*, is the presence of one or several asymmetric carbon atoms in the molecule of every optically active body. It is obvious that two molecules which only differ in that the series of atoms or atomic groups attached to an asymmetric carbon atom differ successively in order of arrangement, which therefore are identical in chemical structure, must be very similar in chemical properties. However, those physical properties, upon which the opposite successive series of atoms or atomic groups in union with asymmetric carbon exerts an influence, *e.g.* the power of deviating the plane of polarized light, must be equal in value, but opposite. The union of two molecules identical in structure, having equal but opposite rotatory power, gives rise to a molecule of an optically inactive polymeric compound.

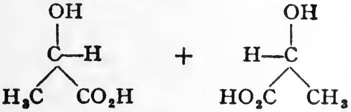
Compounds containing an Asymmetric Carbon Atom.—*a*-Hydroxypropionic acid, $CH_3—{}^*CHOH.CO_2H$, is an example of a compound containing one asymmetric carbon atom. It exists in two optically active, structurally identical, but physically isomeric modifications, and one optically inactive, structurally identical polymeric form:



Dextro-lactic Acid.
(Sarcolactic Acid.)



Lævo-lactic Acid.



{(+) *d*-Lactic Acid (—) *l*-Lactic Acid = } Lactic Acid of Fermentation or Inactive Lactic Acid.

The following compounds also contain one asymmetric carbon atom:—

Leucine	$C_4H_9{*}CH(NH_2)CO_2H$
Malic Acid	$CO_2H.CH_2.{*}CH(OH)CO_2H$
Asparagine	$CONH_2CH_2.{*}CH(NH_2)CO_2H$
Mandelic Acid	$C_6H_5.{*}CHOH.CO_2H$
Coniine	 $CH_2{<}\begin{matrix}CH_2{-}{*}CH\overline{\quad}CH_2CH_2CH_3\\ CH_2{-}CH_2\end{matrix}{>}NH$

Each of the preceding bodies is known in two optically active and one optically inactive modifications.

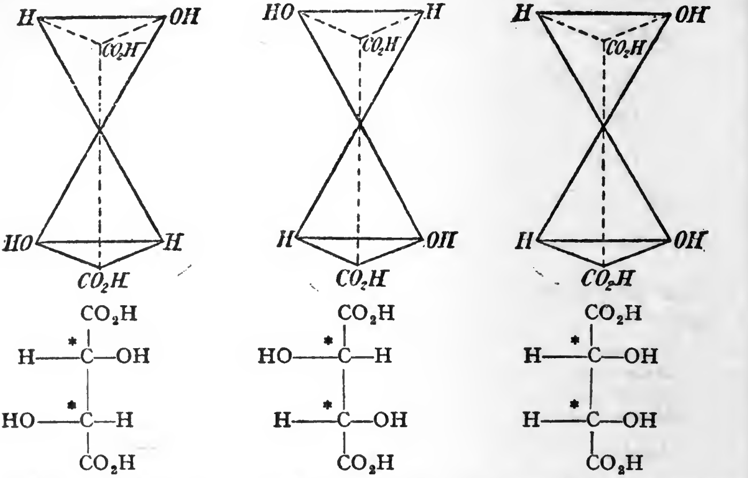
Compounds containing Two Asymmetric Carbon Atoms.—The relations are more complicated when two asymmetric carbon atoms are present.

The simplest case would be that in which similar groups are in union with the two asymmetric carbon atoms. The one half of the molecule would then be constructed chemically exactly like the other half. The four isomeric dihydroxysuccinic acids belong in this group. This group of tartaric acids has become of the greatest importance in the development of the chemistry of optically active carbon derivatives.

They were the first to be most carefully investigated chemically, optically, and crystallographically, and were employed by *Pasteur* in the development of methods for resolving the optically inactive compounds into their optically active components (p. 56). Their importance was further increased by the fact that they were brought into an intimate genetic relation with fumaric and maleïc acids—two isomeric bodies which will be considered in the next section (p. 34).

When a carbon compound contains two asymmetric carbon atoms, united to similar groups, then a fourth compound becomes possible in addition to the three isomeric modifications which a compound containing only one asymmetric carbon atom is capable of forming. If the groups linked to one asymmetric carbon atom, viewed from the axis of union of the two asymmetric carbon atoms, show an opposite successive arrangement to that of the other asymmetric carbon atom, an inactive compound results, due to an *intramolecular* or *internal compensation;* the action due to the one asymmetric atom upon polarized light will be cancelled by an equal but opposite action caused by the other asymmetric carbon atom.

The hypothesis of the asymmetric carbon atom gave the first and, indeed, the only satisfactory explanation for the occurrence of four isomeric symmetrical dihydroxysuccinic acids, which are represented as follows :—



(1) Dextro-tartaric Acid. (2) Lævo-tartaric Acid. (3) Inactive or Meso-tartaric Acid.
Dextro-tartaric Acid + Lævo-tartaric Acid = (4) Racemic Acid.

It is seen that the two independent rotating systems are in contact with one another at one angle of the tetrahedrons through a single carbon bond.

An excellent example of the formation of a meso-form during the purification of two optical antipodes, is supplied by lævo-alanyl-dextro-alanine. It is itself optically active, but loses water, giving rise to the meso-form of alanine anhydride (C. 1906, II. 59) :

l-Alanyl-*r*-alanine. Meso-alanine Anhydride.

The possibilities of isomerism in carbon compounds containing more than two asymmetric carbon atoms—a condition observable with the polyhydric alcohols, their corresponding aldehyde alcohols, and ketone alcohols (the simplest sugar varieties), as well as with their oxidation products, will be more elaborately discussed under these several groups of compounds.

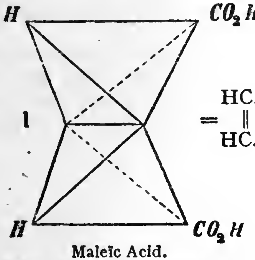
Geometrical Isomerism, Stereoisomerism in the Ethylene Derivatives (*Alloisomerism*).—Two carbon atoms, singly linked to each other, whose valences are not required for mutual union, and which are united to other atoms or atomic groups, may be considered as being able to rotate independently of each other about their axis of union

J. Wislicenus assumes, however, that the atoms or atomic groups combined with these two carbon atoms exercise a "*directing influence*" upon each other until finally the entire system has passed into the "*favourable configuration*" or the "*preferred position.*" It follows from this assumption that, in ethane derivatives in which asymmetric carbon atoms are not present, structurally identical isomers cannot occur. When the *van 't Hoff* tetrahedron models are employed for demonstration the two systems, capable of independent rotation about a common axis, are found to touch one another through a single carbon bond situated at one of the angles (comp. the projection-formula of the tartaric acids, p. 32).

A different state prevails where the carbon atoms are doubly linked. The double union, according to *van 't Hoff*, prevents a free and independent rotation of the two systems and space-isomers are possible. The tetrahedron models represent this double union in such a manner that two tetrahedra have two angles in common and are in contact along a common edge. The frequent and notable differences in chemical behaviour of this class of isomers are to be attributed to the greater or less spacial distance of the atomic groups, which determine the chemical character.

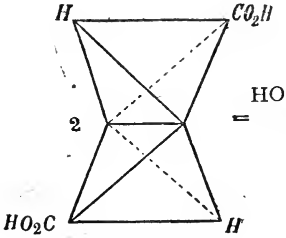
Compounds having the general formulæ $abC{=}Cab$ or $abC{=}Cac$, may exist in two isomeric modifications. In one instance groups of like name are directed towards the same side—according to *J. Wislicenus* the "*plane symmetrical configuration*"—or they are directed towards opposite sides—then they have according to the same author the *central* or *axially symmetrical configuration. Baeyer* suggests for this form of asymmetry the term "*relative asymmetry*" in contradistinction to the kind of asymmetry which substances with asymmetric carbon atoms show; the latter he prefers to call "*absolute asymmetry.*"

The structurally symmetrical ethylene-dicarboxylic acid is the most striking example of this class of isomerism. It exists in two isomeric modifications, known as *fumaric* and *maleïc acids*, both of which have been very carefully investigated. Maleïc acid readily passes into an anhydride, hence the plane symmetrical configuration is ascribed to it; fumaric acid does not form an anhydride, so that the axial symmetrical configuration is given to it, in which the two carboxyl groups are as widely removed from each other as possible. In projection formulæ and in structural formulæ, to which there is given a spacial meaning, the configuration of these two acids would be represented in the following way:—



$$= \begin{array}{c} HC.CO_2H \\ \| \\ HC.CO_2H \end{array}$$

Maleïc Acid.
Plane Symmetrical Configuration.



$$= \begin{array}{c} HO_2C.CH \\ \| \\ H.CO_2H \end{array}$$

Fumaric Acid.
Central or Axially Symmetrical Configuration.

The isomerism of mesaconic and citraconic acids, $(CH_3)(CO_2H)C{=}CH(CO_2H)$, is of the same class; the first acid corresponds to fumaric acid and the second to maleïc acid. Further examples of the class are:

Crotonic and Isocrotonic Acids	$CH_3CH : CHCO_2H.$
Angelic and Tiglic Acids	$CH_3.CH : C(CH_3)CO_2H.$
Oleïc and Elaïdic Acids	$C_8H_{17}CH : CH.C_7H_{14}.CO_2H.$
Erucic and Brassidic Acids	$C_8H_{17}CH : CH.C_{11}H_{22}.CO_2H.$
The two α-Chlorocrotonic Acids	$CH_3.CH : CCl.CO_2H.$
,, ,, β-Chlorocrotonic Acids	$CH_3.CCl : CH.CO_2H.$
,, ,, Tolane Dichlorides	$C_6H_5CCl : CClC_6H_5.$
,, ,, ,, Dibromides	$C_6H_5CBr : CBrC_6H_5.$
,, ,, *o*-Dinitrostilbenes	$NO_2[2]C_6H_4[1]CH : CH[1]C_6H_4[2]NO_2.$
Cinnamic and Allocinnamic Acids	$C_6H_5.CH : CHCO_2H.$
The two α-Bromocinnamic Acids	$C_6H_5.CH : CBrCO_2H.$
,, ,, β-Bromocinnamic Acids	$C_6H_5.CBr : CHCO_2H.$
,, ,, Coumaric Acids	$HO[2]C_6H_4[1]CH : CH.CO_2H$, etc.

Isomeric phenomena of this kind *Michael* designates as *allo-isomerism*, without suggestion as to its cause. When a body passes into a more stable modification upon the application of heat, *Michael* prefixes "allo" to the name of the more stable form; thus, fumaric acid is allomaleïc acid (B. **19**, 1384).

Fumaric and maleïc acids are placed at the head of this class of isomeric phenomena not only because they have been most thoroughly investigated, but chiefly because the two optically inactive dihydroxy-tartaric acids bear to them an intimate genetic relation (p. 31). *Kekulé* and *Anschütz* showed that fumaric acid was converted into racemic acid, and maleïc acid into mesotartaric acid by potassium permanganate. This conversion harmonizes entirely with the *van 't Hoff-Le Bel* conception of these four acids; indeed, it might have been predicted. These relations will be more fully elaborated in the discussion on the acids. In studying maleïc and the alkyl-maleïc acids, it will be further discussed whether or not it is required by configuration that maleïc acid and its homologues should have a structure quite different from that of fumaric acid. The relations are similar in the case of the coumaric acids (Vol. II.).

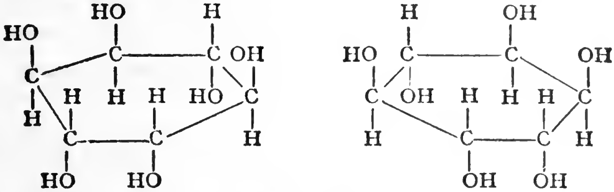
Baeyer considers that the isomerism of the saturated or carbocyclic compounds bears a definite relation to the stereoisomerism of the ethylene derivatives, as will be more fully explained when the hexahydroxyphthalic acids (Vol. II.) are described. The same author maintains that the simple ring-union of carbon atoms viewed from a stereochemical standpoint has the same signification as the double union in open chains. Therefore. stereoisomerism in the carbon compounds with double union would appear merely as a special case of isomerism in simple ring-unions. *Baumann* applied this idea to saturated heterocyclic compounds—to the polymeric thioaldehydes (*q.v.*).

Baeyer suggested the introduction of a common symbol for all geometrical isomers, such as the Greek letter Γ. "The addition of an index will assist the ready expression of the kind of isomerism. In the case of compounds which contain absolute asymmetric carbon atoms, the signs + — can be employed. Thus the expressions

$$\left.\begin{array}{ll}\text{Dextro-tartaric Acid} & = \Gamma + + \\ \text{Lævo-tartaric Acid} & = \Gamma - - \\ \text{Mesotartaric Acid} & = \Gamma + - \end{array}\right\}\text{Tartaric Acid}$$

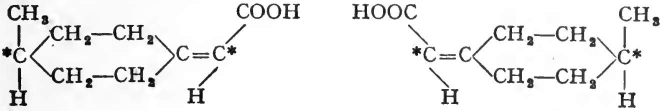
can be understood without special explanation." In the case of relative asymmetry in unsaturated compounds and saturated rings, *Baeyer* proposes to use the terms *cis* and *trans*. Maleïc acid $= r^{cis, cis}$ or briefly r^{cis} ethylene-dicarboxylic acid, while fumaric acid $= r^{cis, trans}$ ethylene-dicarboxylic acid.

Further considerations on the space-configuration of the ethylene and polymethylene derivatives lead to a broadening of the scope and to the correction of the law, that an asymmetric carbon atom must be present in every optically active compound (see above, p. 30). Optical activity can occur even in the absence of an asymmetric carbon atom in the ordinary sense, if *the atoms are attached to a carbon skeleton in such a way in space, that there is no plane of symmetry present*—the object and its mirror-image do not correspond. This is found, for instance, in hexahydrohexahydroxybenzene, which exists in two enantiomorphic optically active forms, as *d*- and *l*- inositol:



d- and *l*- Inositol.

Another example is found in *d*- and *l*- methyl-cyclohexylidene-acetic acid,



in which the CH_3 and H, COOH and H, attached to the *C atoms must lie in planes at right angles to each other as required by the condition of asymmetry (*Aschan*, B. **35**, 3389; *Marckwold* and *Meth*, B. **39**, 1171).

The particularly ready formation of carbocyclic and heterocyclic compounds when five or six carbon atoms take part in the ring formation, is also a result of the position of the atoms in space. This aspect of stereochemistry will be considered in the introduction to the carbocyclic compounds, and there also to the heterocyclic bodies, as well as in the discussion of the cyclic carboxylic esters, or lactones, the cyclic acid amides or lactams, the anhydrides of dibasic acids, etc.

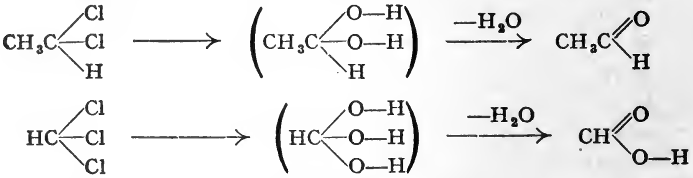
Hypotheses Relating to Multiple Unions of Carbon.—The multiple unions of carbon are so important in stereochemical considerations, that there has been a large amount of research into the nature of this union as well as attempts to represent it. All investigations in this direction demonstrate how difficult it is at present to understand so obscure a force as chemical attraction or affinity from a mechanical point of view. Despite the demand and necessity that may exist for the introduction of hypotheses dealing with the mechanics of multiple linkage the views so far presented are in many essentials contradictory, and not one has won general recognition for itself. See *Baeyer* (B. **18**, 2277; **23**, 1274); *Wunderlich* (Configuration organischer Molecüle, Leipzig, 1886); *Lossen* (B. **20**, 3306); *Wislicenus* (B. **21**, 581); *V. Meyer* (B. **21**, 265 Anm.; **23**, 581, 618); *V. Meyer* und *Riecke* (B. **21**, 946); *Auwers* (Entwicklung der Stereochemie, Heidelberg, 1890), pp. 22–25; *Naumann* (B. **23,** 477); *Brühl* (A. **211,** 162, 371); *Deslisle* (A. **269,** 97); *Skraup* (Wien. Monatsh. **12,** 146); *J. Thiele* (A. **306,** 87; **319,** 129); *Erlenmeyer, jun.* (A. **316,** 43; J. pr. Ch. [2] **62,** 145); *Vorlaender* (A. **320,** 66); *Hinrichsen* (A. **336,** 168).

Stereochemistry of Nitrogen.—Isomeric phenomena of nitrogen-containing compounds of like chemical structure, which could not be ascribed to the same cause as prevailed in carbon compounds, led to the application of stereochemical views to the nitrogen atom. There appeared to be an *absolute nitrogen asymmetry* corresponding to the *absolute carbon asymmetry,* of which examples were cited by *Le Bel* in the unstable, optically active modification of methyl ethyl propyl isobutyl ammonium chloride (C. r. **112,** 724; B. **32,** 560, 722, 988, 1409, 3508; **33,** 1003; C. 1900, II. 77; C. 1900, I. 26, 179; 1901, II. 206, 409, etc.).

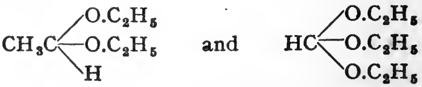
The relative asymmetry, due to the doubly-bound carbon atom, is seen in the isomerism of the oximes (*Hantzsch* and *Werner*; comp. also *Wallach,* A. **332,** 337), of the hydroxamic acids (*Werner*), and of the aromatic diazotates, diazosulphonic acids and diazocyanides (*Hantzsch*).

Stereochemistry of Tin: C. 1900, II. 34. **Stereochemistry of Sulphur:** C. 1900, I. 537; II. 623.

Intramolecular Atomic Rearrangements. — Many investigations have shown that certain modes of linking, apparently possible from a valence standpoint, cannot, in fact, occur, or when they do take place are possible only under certain definite conditions. In reactions, for example, in which two or three hydroxyl groups should unite with the same carbon atom, a loss of water almost invariably occurs and oxygen becomes doubly united with carbon, *e.g.*:

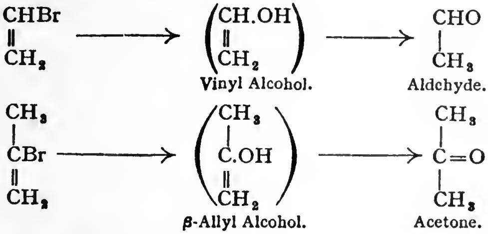


On the other hand, the ethers derivable from these unstable "alcohols" are stable:



In other cases there is a cleavage of a halogen hydride, water or ammonia, with the production of an unsaturated body, or an anhydride of a dibasic acid, or a cyclic ester (*lactone*), or a cyclic amide (*lactam*). In these reactions two molecules result from one molecule, in which atom-groups occur in unstable linkage-relations, an organic molecule and a simple inorganic body.

This type of decomposition of a labile molecule is similar to the phenomenon of *intramolecular atomic rearrangement,* where unstable atomic groupings pass at the moment of their formation into stable forms without the alteration of the size of the molecule. The hydrogen atom, especially, is inclined to wander, but groups, such as the *alkyl, phenyl,* and *hydroxyl* behave similarly. To-day, the number of examples of this phenomenon is remarkably large, of which a few only need be cited. A free hydroxyl group becomes added in most cases to a carbon atom in double union with its neighbouring carbon atom. When intramolecular atomic rearrangements occur the hydrogen of the hydroxyl attaches itself to the adjacent carbon atom, and oxygen of hydroxyl unites doubly with carbon (*Erlenmeyer's* rule, B. **13**, 309; **25**, 1781).



$$\begin{matrix}CHBr\\ \|\\ CH_2\end{matrix} \longrightarrow \left(\begin{matrix}CH.OH\\ \|\\ CH_2\end{matrix}\right) \longrightarrow \begin{matrix}CHO\\ |\\ CH_3\end{matrix}$$

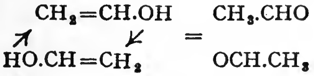
Vinyl Alcohol. Aldehyde.

$$\begin{matrix}CH_3\\ |\\ CBr\\ \|\\ CH_2\end{matrix} \longrightarrow \left(\begin{matrix}CH_3\\ |\\ C.OH\\ \|\\ CH_2\end{matrix}\right) \longrightarrow \begin{matrix}CH_3\\ |\\ C=O\\ |\\ CH_3\end{matrix}$$

β-Allyl Alcohol. Acetone.

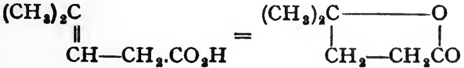
However, the ethers obtained from vinyl alcohol (*q.v.*) are stable: $CH_2=CHO.C_2H_5$ and $CH_2=C(O.C_2H_5)—CH_3$ are known.

It has also been observed that a transposition such as that described above can occur by two unstable and similar molecules rearranging with each other, so that two similar stable molecules result:



$$\begin{matrix}CH_2=CH.OH\\ \nearrow \qquad \swarrow\\ HO.CH=CH_2\end{matrix} = \begin{matrix}CH_3.CHO\\ \\ OCH.CH_3\end{matrix}$$

A rise of temperature is frequently necessary to induce many of these reactions to take place. Both compounds are capable of existence. Unsaturated acids pass into lactones. The intramolecular atomic rearrangement proceeds in a direction favouring the formation of a stable ring:

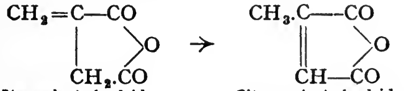


Isocaprolactone.

In other unsaturated compounds we observe that the unsymmetrical is transformed into a symmetrical body through the rearrangement of the double linking of carbon:

$$\underset{\text{Allyl Iodide.}}{CH_2:CH.CH_2I} \xrightarrow{KCN} CH_2:CH.CH_2.CN \rightarrow \underset{\text{Nitrile of Crotonic Acid.}}{CH_3.CH:CH.CN} \rightarrow$$

$$\underset{\text{Crotonic Acid.}}{CH_3.CH:CH.CO_2H}$$



Itaconic Anhydride. Citraconic Anhydride.

The esters of hydrothiocyanic acid, under the influence of heat, rearrange themselves into the isomeric mustard oils, sulphur unites doubly with carbon and the alcohol radical that had previously been in union with the sulphur wanders to nitrogen:

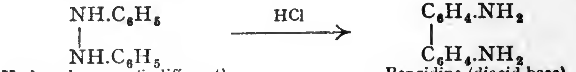
$$\underset{\text{Allyl Thiocyanate.}}{C_3H_5—S—C{\equiv}N} \longrightarrow \underset{\text{Allyl Mustard Oil.}}{S=C=N.C_3H_5}$$

Isonitriles or carbylamines, when heated, pass into nitriles; the alcohol radical previously in union with nitrogen, wanders to carbon:

$$C_6H_5—N=C \longrightarrow C_6H_5—C\equiv N.$$

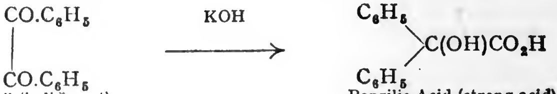
Phenyl Carbylamine. (Vol. II.) Benzonitrile. (Vol. II.)

Other rearrangements among the atoms of compounds only take place in the presence of a strong acid or base. Indifferent bodies pass over into basic or acid compounds:



$$\begin{matrix} NH.C_6H_5 \\ | \\ NH.C_6H_5 \end{matrix} \xrightarrow{HCl} \begin{matrix} C_6H_4.NH_2 \\ | \\ C_6H_4.NH_2 \end{matrix}$$

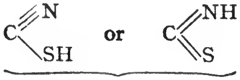
Hydrazobenzene (indifferent). Benzidine (diacid base).



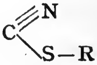
Benzil (indifferent). Benzilic Acid (strong acid).

Further examples of intramolecular rearrangements of aromatic bodies are diazobenzoic acid, phenylhydroxylamine, diazoamido-compounds, etc. (see Vol. II.).

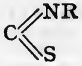
Pseudo-forms, Pseudomerism, Desmotropy, Merotropy, Tautomerism, Phasotropism.—The study of these intramolecular atomic migrations led to the recognition of a large number of atomic groups as being labile and stable. In the case of many bodies it became known that apparently they could react in accordance with *two different formulæ.* In other words, as our constitutional formulæ were deduced from chemical behaviour, it may be said that compounds existed to which two, and under certain circumstances more, constitutional formulæ could be ascribed. *Baeyer* (B. **16,** 2188) explained this phenomenon in such a manner that the stable bodies, under the influence of heat or reagents, passed into unstable modifications. "These isomers are only known in compounds; in the free state they revert to the original form. Their instability is referable to the mobility of the hydrogen atoms, since the replacement of the latter is followed by stability" (compare *A. W. Hofmann,* B. **19,** 2084). Mention may be here made of:



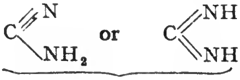
Hydrothiocyanic Acid. Isothiocyanic Acid.



Known.



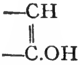
Known (mustard oils).



Cyanamide. Carbodi-imide.

Known.

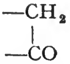
Known.



$$\begin{matrix} —CH \\ \| \\ —C.OH \end{matrix}$$

Hydroxyl or Enol Form (J. pr. Ch. [2] 50, 123).

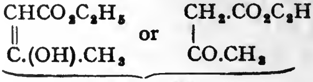
or



$$\begin{matrix} —CH_2 \\ | \\ —CO \end{matrix}$$

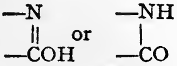
Ketone Form.

e.g.



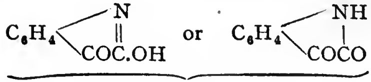
$$\underbrace{\begin{matrix} CHCO_2C_2H_5 \\ \| \\ C.(OH).CH_3 \end{matrix} \text{ or } \begin{matrix} CH_2.CO_2C_2H_5 \\ | \\ CO.CH_3 \end{matrix}}$$

Acetoacetic Ester.



$$\begin{matrix}-N \\ \| \\ -COH\end{matrix} \quad \text{or} \quad \begin{matrix}-NH \\ | \\ -CO\end{matrix}$$

Lactime Form. Lactam Form.

e.g. 

Isatine.

Baeyer proposes to represent the unstable modifications by the designation "*pseudo*." *Pseudomerism* is the term that will be adopted in this work for the phenomenon in which one and the same carbon compound can react in accordance with different structural formulæ. The unstable form of a derivative will, therefore, take the name "pseudoform" or "pseudo-modification." In some instances both forms are known.

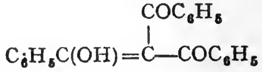
Closely related to the conception of pseudomerism is that of *Desmotropy*, derived from δεσμός, a bond, and τρέπειν, to change (*P. Jacobson*, B. **20**, 1732, footnote; **21**, 2628, footnote; *L. Knorr*, A. **303**, 133; *Hantzsch*, B. **20**, 2802; **21**, 1754; *Förster*, B. **21**, 1857). *Michael* suggested the name "*Merotropy*" (B. **27**, 2128, footnote; J. pr. Ch. [2] **45**, 581, footnote; **46**, 208).

It is noteworthy that most pseudomeric compounds are acid in character; they can form salts. When these salts are treated with alkylogens or acyl halides the two classes of isomers appear. *H. Goldschmidt* (B. **23**, 253) refers this phenomenon to the appearance of free ions. Hence in passing judgment upon questions of pseudomerism only those reactions can be considered, from which electrolytic dissociation is excluded. *Michael* (J. pr. Ch. **37**, 473) puts forward the noteworthy suggestion that in the transpositions of the salts by organic halides two independent processes, depending on the conditions present, take place: that there is a simple exchange whereby the organic radical takes the place of the metal; or the radical halide first adds itself to the molecule and subsequently separates as a metallic halide. In the latter case the organic radical assumes a position different from that previously held by the metallic atom (compare acetoacetic ester and malonic ester). *Nef* has recently maintained the correctness of *Michael's* view.

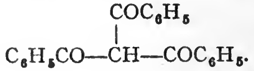
Laar, on the contrary, following *Butlerow* (A. **189**, 77), *van 't Hoff* (Ansichten über die organische Chemie, **2**, 263) and *Zincke* (B. **17**, 3030), assumes that such compounds consist of a mixture of structural isomers, in that an easily mobile hydrogen atom oscillates between two positions *in equilibrio*, and thereby the entire complex becomes mobile. He designates the phenomenon as *tautomerism*. Discarding the uncertainty introduced into the classification of the carbon compounds by the acceptance of this view, it has been noted that carbon compounds which *Laar* considers mixtures of structurally isomeric bodies do not differ in their physical properties from carbon compounds which offer no place in their structure for this equivocal assumption. By the assumption of tautomerism with the underlying meaning assigned it by *Laar*, the experimental solution of the problem as to the conditions under which pseudo-forms are capable of existence is without object. Although from the nature of the case the identification of easily alterable intermediate reaction-products must continue to be one of the most difficult problems, yet success has been met with in quite a number of cases. At a time when chemical investigations at very low temperatures can so easily be carried on by means of readily obtainable liquid air, experiments on the conditions of existence of labile modifications will be started afresh.

The preceding section was prepared in 1893. Since then, numerous confirmations of these views have been found. The *ketones* constitute the most important class of compounds, which are tautomeric. In them, as in acetoacetic ester, the oscillation is between the paraffin ketone and the olefine hydroxyl or enol formula (p. 40).

The investigations of *Claisen* (A. **291**, 25; **297**, 1), *Guthzeit* (A. **285**, 35), *W. Wislicenus* (A. **291**, 147), *Knorr* (A. **293**, 70; **303**, 133; **306**, 332), *P. Raabe* (B. **32**, 84), *Dimroth* (A. **335**, 1), and others have demonstrated that there exist compounds of the form—C(OH)=C—CO—, which readily pass into the form—CO—$\overset{|}{C}H$—CO—, and conversely are easily produced from the latter: "The character of the added residue, the temperature and the nature of the solvent, in the case of dissolved substances, determine which of the two forms will be the more stable." *Claisen* designates the acidic *enol*-form the α-compound and the neutral *keto*-form the *β*-body, *e.g.*

α-Tribenzoyl Methane 

$$C_6H_5C(OH)=\overset{\overset{COC_6H_5}{|}}{C}—COC_6H_5$$

β-Tribenzoyl Methane 

$$C_6H_5CO—\overset{\overset{COC_6H_5}{|}}{C}H—COC_6H_5.$$

The system of nomenclature proposed by *Hantzsch* for pseudomeric substances (B. **38**, 1000) appears to be most suited for its purpose. If the accustomed name refers to a "pseudo-acid" (the weaker acid or neutral form), then the name of the real acid is characterized by the prefix "aci"; for instance, $CH_3CO—CH_2—COOC_2H_5$ is called acetoacetic ester, and $CH_3C(OH)=CH—COOC_2H_5$ is named *aci*-acetoacetic ester.

If the usual name denotes the strong acid, then that of the pseudo-acid is prefixed by the word "pseudo," as, for example, $\overline{\overset{|}{C}H_2.C(OH)=CH—CO.\overset{|}{O}}$ is called tetronic acid, and $\overline{\overset{|}{C}H_2.CO—CH_2—CO.\overset{|}{O}}$ is *pseudo*-tetronic acid.

Claisen was the first to show that, in the above example of the two tribenzoyl methanes, only compounds having the α- or aci- constitution form salts direct; the *β*- or pseudo-form yields no salts of the type $\dot{C}O—\dot{C}Me—\dot{C}O$, but gradually changes when in contact with bases, into the salt of the aci-form $\dot{C}O—C=C(OMe)$ (see p. 41; slow or time isomerisation phenomena).

The change of phenyloxybiazole carboxylic acid ester from one pseudomeric form into the other has been quantitatively determined by *Dimroth* by titration with potassium iodo-iodate. He found that only the aci-form precipitated iodine while forming a salt, and that the pseudo-form remained unaltered.

Substances such as acetoacetic ester, malonic ester and others possessing the grouping—$CO—CH_2—CO$— are considered to exist in the pseudo-form, since only one form has been isolated, and this yielded no salts of its own; those which have been obtained, are metallic hydroxyl-substitution compounds of the aci-form.

The phenomenon of pseudomerism in these compounds can be further complicated by the intervention of stereoisomerism (p. 32) in enol-forms (see Diacetosuccinic acid ester, *Knorr*, A. **306**, 332; Formyl phenyl acetic ester, Z. phys. Ch. **34**, 46, etc.; on the other hand, see *Michael*, B. **39**, 203).

Physical methods have proved exceedingly helpful in determining the constitution of the pseudomers, and in following the mutual interchange of forms. Molecular refractions in particular have been determined, as, for instance, in the case of acetoacetic ester and its salts (*Brühl*, J. pr. Ch. [2] **50**, 119; B. **38**, 1868; *Haller* and *Muller*,

C. 1905, I. 349, etc.) ; as well as dielectrical constants (*Drude*, *Z.* phys. Ch. **23,** 308), and the magnetic rotation (*Perkin, Sen.*).

The investigations of *Holleman* (B. **33,** 2912) and of *Hantzsch* have enabled the presence of pseudomerism to be detected by electric conductivity measurements. This is only possible when one of the two possible forms is a weaker electrolyte than the other, as, for example, in the case of certain nitro-fatty bodies –$R.CH_2NO_2$, $R.CH(NO_2)_2$. Such compounds are gradually changed by alkalies into isonitro-bodies, RCH=NOOMe, etc. ; and from these salts the addition of the equivalent quantity of hydrochloric acid liberates the isonitro-body itself. In solution these iso-compounds revert to the true nitro-body with a greater or less velocity which can be followed by the diminution in electric conductivity, and the gradual disappearance of the red colour given with ferric chloride, which is a general characteristic for the aci-form of a compound (slow or time isomerization phenomena, B. **39,** 2089, 3149, 2265).

Chromopseudomerism or *Halochromism* is the name given to the phenomenon of a colourless or feebly coloured substance yielding a strongly coloured salt with colourless bases or acids. Such an occurrence was referred by *Hantzsch* (B. **39,** 3080) to pseudomerism, where a colourless pseudo-electrolytic radical yielded a coloured ion. Examples of this are found in the coloured salts of nitroform, violuric acid, etc.

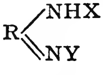
Halochromism is specially developed in the ortho- and para-derivatives of the benzene series (see Vol. II.), which behave, on the one hand, like the mostly colourless true benzene compounds, and on the other like the mainly strongly coloured derivatives of quinone ; this class of bodies includes *o*- and *p*- nitroso- and nitrophenols, *o*- and *p*- amino- and oxyazo- bodies, derivatives of triphenyl carbinol, etc., classes of bodies to which the coal tar dyes belong, to which the study of pseudomerism is of special importance. *V. Baeyer* and others (B. **38,** 570 ; **39,** 2977) consider halochromism can also occur in certain cases without any real alteration in structure occurring. This is brought about by one of the ordinary carbon valences changing into a so-called *carbonium* valence, which *Baeyer* represents by a wavy line ; as for example :

$(C_6H_5)_3C—OH$
Triphenyl Carbinol,
colourless.

$(C_6H_5)_3C\sim\!\sim\!\sim O.SO_3H.$
Triphenyl Carbinyl Sulphate,
coloured.

In all the cases which have been considered, the interchangeable isomers have belonged to two different classes of compounds with quite different chemical characteristics. There exist, however, substances which according to their mode of preparation should give rise to two forms belonging to the same class, but which have turned out to be identical with one another, as, for example, diazoamido-compounds, amidines, formazyl derivatives of the general type—

and



where R represents N in diazoamido bodies, CH in the amidines, and N : CH.N in the formazyl derivatives. This explains the absence of certain isomerism phenomena in pyrrole, and such azoles as pyrazole and triazole (see Vol. II.), and also in the ortho-di-derivatives of benzene (Vol. II., the Constitution of Benzene), etc. Attempts have been made to explain these phenomena by assuming *oscillations* of *Kekulé's* valences (*Knorr*, A. **279**, 188); and this is further complicated, in the case of pyrrole and the azoles, by the wandering of a H atom. For the phenomenon itslef *Brühl* suggests the name *Phasotropism* (B. **27**, 2396), whilst *V. Pechmann* puts forward the term *virtual tautomerism* (B. **28**, 2362).

THE NOMENCLATURE OF THE CARBON COMPOUNDS

The steadily increasing number of carbon derivatives has shown the absolute necessity that definite principles should determine their designation. The absence of such general and international rules (where they were possible) has led to great confusion in the nomenclature.

Compounds originating from plants and animals received names that indicated their origin, and often at the same time their characteristic chemical properties: urea, uric acid, tartar, tartaric acid, formic, oxalic, malic, citric, salicylic acids, etc. With a large class of bodies, *e.g.* the bases, glucosides, bitter principles, fats, etc., it was customary to employ the ending "ine": coniine, nicotine, guanidine, creatine, betaïne, salicine, amygdaline, glycerine, stearine, etc., and in the terminations al, ol, an, en, yl, ylene, ylidene, the effort was made to show the similarity of certain compounds, without, however, proceeding in a connected way.

The more thoroughly the constitution of bodies became known, the greater was the desire to indicate by names the manner in which the atoms were united. This was especially true in the case of isomeric compounds. The manner in which this was done, however, was left to the choice of the individual, and thus it happened that often one and the same derivative received different names, which possessed fundamentally equivalent meanings.

Of the early suggestions on nomenclature, that of *Kolbe* (A. **113**, 307) on *carbinol* deserves special consideration. As is known, *Kolbe* referred the names of the monohydroxy saturated alcohols back to the name *carbinol*. In order to make this principle more general, it becomes necessary to ascertain the carbinol or carbinols for each class of compounds—that is, to find those bodies from which the homologues might be derived, just as the monohydroxy saturated alcohols might be deduced from methyl alcohol or carbinol. Without attempting at this time to determine the limits of the "carbinol nomenclature," it will suffice to remark that in the case of the paraffin dicarboxylic acids all the normal homologues are the carbinols; *e.g.* malonic acid, succinic acid, normal glutaric acid, adipic acid, etc. Indeed, names such as monomethyl malonic acid, ethyl methyl malonic acid, symmetric and unsymmetric dimethyl succinic acid, etc., are so readily understood that they are preferred by many chemists.

In order to minimize as far as possible the arbitrary nomenclature of organic compounds, a meeting was convened in Geneva, in 1892, of the chemists of nearly all the civilized countries, for the purpose of agreeing on a method of indicating the constitution of carbon compounds in a consistent and clear manner. The new "official" names adopted by the Geneva Convention will, in the case of certain important series of compounds, be observed in the present text; they will be enclosed in brackets—*e.g.* [ethene] for ethylene, [ethine] for acetylene, etc. The designations of the simpler bodies—the names justified from an historical standpoint and deduced from important reactions—will not be wholly eliminated. Thus, the names ethyl hydride, dimethyl or methyl methane will be used for ethane, depending upon what relations are especially to be emphasized.

The new nomenclature proceeds from, or begins with, the hydrocarbons. The name of the hydrocarbon serves as the *root* for the names of those substances which contain their carbon atoms arranged in a similar manner. The different classes of bodies are distinguished by the addition of suffixes to the names of the hydrocarbons: alcohols end in *ol*, aldehydes in *al*, ketones in *one*, and the acids in *acid*—*e.g.* [ethanol] = ethyl alcohol, [ethanal] = acetaldehyde, [propanone] = acetone, [propanal] = propionic aldehyde, [ethane-acid] = acetic acid. These examples will suffice. The more detailed consideration will be given to the various classes of bodies, which are discussed. The principles of this nomenclature have already been found difficult of application, especially in attempting to indicate in name a compound having a mixed character—*e.g.* the body COH—CH_2—CHOH—CO—CO_2H, which would be *pentanolalone-acid.* The accumulation of suffixes, each of which possesses a meaning peculiar to itself, has " conduit rapidement à des termes bizarres, d'une complication facheuse et d'une prononciation difficile " (*Amé Pictet*).

For the decisions of the International Congress of Geneva, convened 19th to 22nd April, 1892, for the purpose of co-ordinating chemical nomenclature, see *Tiemann* (B. **26**, 1595): *Istrate's* proposals (C. 1898, I. 17). On the nomenclature of ring-compounds, see Vol. II.; also *M. M. Richter* (B. **29**, 586).

In order to distinguish the more frequently occurring radicals of the same kind, such as the univalent hydrocarbon residues, both aliphatic and aromatic, the name *alkyl* has been accepted. In differentiating between the two classes *alphyl* refers to the aliphatic residues and *aryl* to the aromatic; whilst aromatic residues possessing aliphatic characteristics are referred to as *alpharyle.* Carboxylic acid residues, too, are referred to as *acyl* and differentiated into *alphacyl* and *aracyl* (C. 1899, I. 825).

PHYSICAL PROPERTIES OF THE CARBON COMPOUNDS

It can, in general, be foreseen that the physical as well as the chemical properties of carbon compounds must be dependent on their composition and constitution. Such a regular connection has, however, only been determined for a few properties, of which the following serve chiefly for external characterization :—

1. Crystalline form.
2. Specific gravity, density.
3. Melting point.
4. Boiling point.
5. Solubility.

For the investigation of constitution the following properties are of importance :—

6. Optical properties.
    - (*a*) Refraction.
    - (*b*) Dielectric constants.*
    - (*c*) Optical rotation.
    - (*d*) Magnetic rotation.
7. Electrical conductivity.

1. CRYSTALLINE FORM OF CARBON COMPOUNDS

The crystalline form of a carbon derivative is one of its most important distinctions, whereby a body may be recognized most definitely and differentiated from other substances; so that the preparation of organic substances in the form of crystals and their examination has been of the greatest value in organic chemistry. The more complex the constitution of a substance, the less the symmetry of its crystals (B. **27**, R. 843). *The crystalline forms of isomeric bodies are always different.* Many substances may assume two or more forms; they are *dimorphous, polymorphous,* but each is characterized very definitely by particular conditions of formation and existence.

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* This is, strictly, an electrical constant, but owing to its close connection with optical refraction, it is convenient to include it here, as in the German edition. (Translator's note.)

When it is possible for a compound to crystallize from the same solvent in different forms, only one can separate within definite ranges of temperature. The limit between these zones, the *temperature of transformation*, is theoretically expressed by the point of intersection of the solubility curves of the two crystalline forms. It is only the one or the other form that can appear under normal conditions above or below this temperature. From a supersaturated solution, and indeed a supersaturated solution of the two forms, it is possible by the introduction of one or the other form, to obtain each of the two kinds of crystals, and, indeed, both together, but only so long as the supersaturation continues. After that, one of the two forms will gradually dissolve and that one will remain which is the more stable at the temperature of experiment. The temperature of transformation varies for each solvent, and when impurities are present in the substances a greater or less variation in the temperature will occur, according to the degree of impurity.

The existence and stability of a definite modification of a polymorphic substance depends to a great extent on the temperature, of which the influence, however, is not always the same. In the case of perchlorethane C_2Cl_6, rhombic, triclinic, and regular crystal forms are successively assumed during a gradual rise in temperature, whilst on cooling, the same series is passed through in reversed order. The change is said, therefore, to be *reversible*, and polymorphic substances of this kind are called *enantiotropic* (*Lehmann*). With other bodies, however, one modification may be labile and the other stable, so that the first form changes into the second, and not *vice versâ*. As an example, paranitrophenol $C_6H_4.OH.NO_2$ (1,4) may be taken. On solidification from the molten state, or from a hot solution, it crystallizes in the colourless labile form. This, on standing, turns into the stable yellowish-red modification, which is quite different in its cleavage and optical properties from the first. It can also be obtained by crystallizing from a cold solution. Such substances, which undergo a change in one direction only, are called *monotropic*. In many cases, however, a rigid grouping of the numerous polymorphic organic bodies in one or other of the two groups is not always easy. For the assumptions necessary for the explanation of the phenomenon, see *Zincke* (A. **182**, 244) and *Lehmann* (Molecular physik, Leipzig, 1888/89); *Graham-Otto* (Lehrbuch der Chemie, Vol. I., Part 3, p. 22, 1898).

At the present time little is known about the inner connection between the crystalline form and chemical constitution of carbon compounds, but it has been found, for example, that the slightest variation in chemical constitution does affect the amount of rotation exhibited by optically active compounds. Many such substances possess a hemihedral form, and the two optically active modifications of a carbon compound, although they exhibit the same geometrical constants, are distinguished by peculiar left and right types (*enantiomorphous* forms); they are not superposable. The difference between two such compounds, in which the atoms are similarly united, is only due, according to the hypothesis of an *asymmetric* carbon atom (p. 30), to the difference in arrangement of the atoms within the molecule. From this it follows that this variation in arrangement finds expression in the crystalline form (comp. B. **29**, 1692).

Laurent, *Nicklès*, *de la Provostave*, *Pasteur*, *Hjortdahl* (see F. N. Hdw. **3**, 855) investigated the influence that chemical relations of organic bodies exerted upon the geometrical properties of their crystals. This problem, however, first appeared in the forefront of crystallographic study after *P. Groth* introduced the idea of *morphotropy* (Pogg. A. **141**, 31). By this term was understood the phenomenon of regular alteration of crystalline form produced by the entrance of a new atom or atomic group for hydrogen. *Groth*, *Hintze*, *Bodewig*, *Arzruni*, and others frequently called attention to such morphotropic relations particularly with the aromatic bodies (comp. Physikal. Chemie der Krystalle von *Andreas Arzruni*, 1893).

The recognition of the connection between crystalline form and chemical constitution is rendered more difficult by the fact that as yet an accurate determination of the magnitude of the crystal-molecule or crystal-element cannot be made. The possibility of doing this in the future may perhaps be found in *van 't Hoff's* theory of solid solutions. As to the *rôle* of water of crystallization in the salts of organic acids, consult Z. phys. Ch. **19**, 441.

2. SPECIFIC GRAVITY OR DENSITY

By this term is understood the relation of the absolute weight of a substance to the weight of an equal volume of a standard body. Conventional units of comparison are water for solids and liquids, and air or hydrogen for gaseous bodies (see p. 11). The number representing the specific gravity of a compound is as great as that representing its density. It frequently occurs, therefore, that the terms specific gravity and density are used interchangeably.

Density of Gaseous Bodies.—For these, as we have already seen, the relation of the specific gravity (gas density) to the chemical composition is very simple. Since, according to Avogadro's law, an equal number of molecules are present in equal volumes, the gas densities stand in the same ratio as the molecular weights. Being referred to hydrogen as unit, the gas densities are one-half the molecular weights. Therefore, the *molecular volume, i.e.* the quotient of the molecular weight and specific gravity, is a constant quantity for all gases (at like pressure and temperature).

Density of Liquid and Solid Carbon Derivatives.—In the liquid and solid states the molecules are considerably nearer each other than when in the gaseous condition. The size of the molecules and their distance from each other, which increases in different degrees with rise of temperature, are unknown, so that the theoretical bases for deducing the specific gravity are lacking. However, some regularities have been established empirically, which, by comparison with the specific or molecular volumes, give the ratio of molecular weight to specific gravity.

The relations between the specific volumes of carbon compounds were first systematically studied by *H. Kopp*, in 1842 (A. **64**, 212 ; **92**, 1 ; **94**, 257 ; **96**, 153, etc., to **250**, 1). He felt justified from his observations in proposing : "That the specific volume of a liquid compound (molecular volume) at its boiling point is equal to the sum of the specific volumes of its constituents (of the atomic volumes), and that every element has a definite atomic volume in its compounds."

From this it would follow that : (1) Isomeric compounds possess approximately like specific volumes ; (2) like differences in specific volumes correspond to like differences in composition.

The more recent researches (*Lossen* and others (A. **214**, 81, 138 ; **221**, 61; **224**, 56 ; **225**, 109 ; **233**, 249, 316 ; **243**, 1) ; *R. Schiff* (A. **220**, 71, 278) ; *Horstmann* (B. **19**, 1579 ; **20**, 766 and **21**, 2211, etc.), based upon an abundance of material, and at the same time giving due consideration to the structural relations of the carbon compounds, prove conclusively that the supposed regularities, mentioned above, are unfounded. In fact, isomeric compounds do not possess equal molecular volumes, and their atomic volumes are not constant. The volume for the difference CH_2 is not constant in the different homologous series, nor is that of hydrogen (A. **233**, 318 ; B. **20**, 767), nor that of oxygen (A. **233**, 322 ; B. **19**, 1594). *M. W. Richards* has shown that the atomic volume is a function of temperature and pressure, and probably, also, of electric potential (Z. phys. Chem. **40**, 169). For the molecular solution-volume, see *Traube* (A. **290**, 43 ; B. **28**, 2722).

Hence the molecular volumes do not represent the sums of the atomic volumes (the latter are scarcely determinable), and the specific gravities and molecular volumes depend less upon the volume of the atoms than upon their manner of linkage and upon the structure of the molecules. Therefore, to deduce regularities in the specific volumes it is first necessary to consider carefully the chemical structure of the compounds. In this connection the influence of the double union of the C- atoms in the unsaturated compounds and the ring-linkage in the benzene derivatives, is significant. Assuming that the molecular volume of hydrogen is known and is equal to 5·6, it becomes possible to calculate the molecular volume of an unsaturated olefine compound if the molecular volume of the corresponding saturated paraffin body is known. Thus, pentane =117·17; therefore amylene =117·17−2×5·6=105·97. In fact, the molecular volume of amylene equals 109·95. Consequently 109·95−105·97=3·98—the increase in molecular volumes caused by the double linkage in amylene (A. **220**, 298; **221**, 104; B. **19**, 1591; **20**, 779). The divalent union is therefore less intimate (pp. 21, 35), and the unsaturated compounds consequently show a greater heat of combustion (A. **220**, 321).

In the conversion of benzene hydrocarbons into their hexahydrides there is an increase in volume which is three times as great as in the conversion of the olefines into their corresponding paraffins. This would emphasize the theory that in the benzene nucleus there are three doubly-linked carbon atoms. The specific gravities of the benzene hexahydrides are notably greater (consequently the molecular volumes are smaller) than those of their corresponding olefines, and that accounts for the fact that in the ring-linking of the C- atoms in the benzene nucleus there is an appreciable contraction in volume (A. **225**, 114 and B. **20**, 773); *Horstmann* (B. **21**, 2211); *Neubeck* (Z. phys. Chem. **1**, 649).

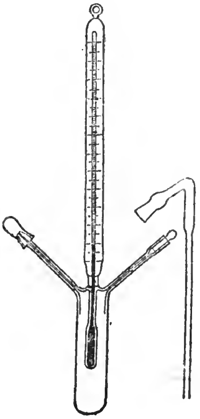


Fig. 7.

Schroeder determined the specific volumes of a number of solids (B. **10**, 848, 1871; **12**, 567, 1613; **14**, 21, 1607, etc.).

In determining the specific gravity of liquid compounds, a small bottle—a pyknometer—is used, of which the narrow neck carries an engraved mark. More complicated apparatus, such as that designed by *Brühl*, based on *Sprengel's* form, is employed where greater accuracy is sought (A. **203**, 4) (Fig. 7). Descriptions of modified pyknometers will be found in Ladenburg's Handwörterbuch, **3**, 238. A convenient form by *Ostwald* is described in J. pr. Ch. **16**, 396. To obtain comparable results, it is recommended to make all determinations at a temperature of 20° C., and refer these to water at 4° and a vacuum. If *m* represents the weight of substance, *v* that of an equal volume of water at 20°, then the specific gravity at 20° referred to water at 4° and a vacuum (with an accuracy of four decimals), may be ascertained by the following equation (A. **203**, 8):—

$$d_4^{20} = \frac{m \,.\, 0{\cdot}99707}{v} + 0{\cdot}0012.$$

To find the specific volumes at the boiling temperature, the specific gravity at some definite temperature, the coefficient of expansion and the boiling point must be ascertained; with these data the specific gravity at the boiling point is calculated, and by dividing the molecular weight by this, there results the *specific* or *molecular volume*. *Kopp's* dilatometer (A. **94**, 257), *Thorpe* (J. Ch. S., **37**, 141), *Weger* (A. **221**, 64), is employed in obtaining the expansion of liquids. For a method of obtaining the direct specific gravity at the boiling point, see *Ramsay* (B. **12**, 1024), *Schiff* (A. **220**, 78; B. **14**, 2761), *Schall* (B. **17**, 2201), *Neubeck* (Z. phys. Ch., **1**, 652).

Kanonnikow, as well as *Kopp* and his followers, employed the "true density" in his calculations, not the figure as found directly. This he took as being the reciprocal of *Lorenz's* refraction constant, since, according to the *Clausius* and *Mosotti* theory, it constitutes the fraction of the total volume of a body which is actually occupied by the molecules themselves (C. 1899, II. 858; 1901, I. 1190).

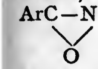
3. MELTING POINT (FUSION POINT BP.)

Every pure compound, if at all fusible or volatile, exhibits a definite melting temperature. It is customary to determine this for the characterization of the substance, and as a test of its purity. The melting point of a pure compound is not changed by recrystallization. The slightest impurities frequently lower the melting point very considerably, whereas when foreign substances are present in larger amounts the melting point is irregular and not well defined—*i.e.* there is not a definite melting point. If two different substances have the same melting point, a mixture of them will show a considerably lowered melting point. The converse of this is of importance when establishing the identity of two bodies—the mixture must have the same melting point as each of the separate substances. Pressure influences the melting point to a very slight degree.

In many crystalline carbon compounds a double melting point is observed. When heated, the substance first melts to a doubly refracting, turbid " crystalline liquid " (L_1), which becomes clear and isotropic at a higher temperature (L_2, the " clearing point "). On cooling the reverse order of changes may be observed :

$$\text{Solid crystals} \overset{L_1}{\rightleftarrows} \text{" Crystalline liquid "} \overset{L_2}{\rightleftarrows} \text{Amorphous liquid.}$$

The phenomenon apparently depends on chemical constitution, and is observed mainly in aromatic compounds, chiefly acids, acid esters, ketones, and phenolic ethers, which belong to the azoxy- or azo- series, or which contain the group



$$\underset{\searrow O \swarrow}{\text{ArC}-\text{NAr}}$$

or ArC=NAr; and also in the cholesterol compounds, etc. (see B. **39**, 803, bibliography; Z. phys. Ch. **57**, 357).

Determination of the Melting Point.—The most accurate method would be to immerse the thermometer in the molten substance ; this, however, would require large quantities of material (*Landolt*, B. **22**, R. 638).

Ordinarily, a small quantity of the finely pulverized material is introduced into a capillary tube, closed at one end, which is attached to a thermometer, for instance by a thin platinum wire, in such a way that the thermometer and capillary tube are on the same level. Alternatively, the substances may be pressed between two cover glasses (C. 1900, I. 241). A beaker containing sulphuric acid or liquid paraffin is used to furnish the heat, which is kept uniform throughout the liquid by agitation with a glass stirrer. A long-necked flask, containing sulphuric acid, is sometimes employed, in which a test tube is inserted or fused : in the latter case it is necessary that the flask should be provided with a side-tubulure (Fig. 8) (B. **10**, 1800; **19**, 1971; **5**, 337; C. 1900, II. 409).

When the mercury thread of the thermometer extends far above the surface of the bath, it is necessary, in accurate determinations, to introduce a correction, by adding the value $n(T-t)$ 0·000154 to the observed point of fusion, where n is the length of the mercury column projecting beyond the bath expressed in degrees of the thermometer, T is the observed temperature, and t the temperature registered in the middle of the projecting portion of the mercury column ; 0·000154 is the apparent coefficient of expansion of mercury in glass (B. **22**, 3072 : Literature and Tables). After the melting point has been approximately determined with an ordinary thermometer a more accurate determination may be made by introducing a shorter thermometer, divided into fifths, with a scale carrying a limited number of degrees (about 50°). (See Fig. 8.)

The lack of agreement between the melting points of the same compound as determined by different workers, is often sufficient to prevent identification. This is not so much due to the thermometers as to the manner in which the determination is made. By rapid heating the mercury of the thermometer will not have time to assume the fusion temperature. In the region of the melting point the heat must be moderated so that during the course of the fusion the thermometer rises *very* slowly. Far more concordant figures might be obtained if a general use of short-scale thermometers were adopted and the *time* agreed upon for the mercury of the thermometer to rise through one degree of the scale during the observation. For the determination of low melting points by means of the air thermometer, see B. **26**, 1052; B. **33**, 637. For the determination of the melting points of organic bodies fusing at high temperatures, see B. **28**, 1629; at red-heat, B. **27**, 3129; of coloured compounds, B. **8**, 687; **20**, 3290.

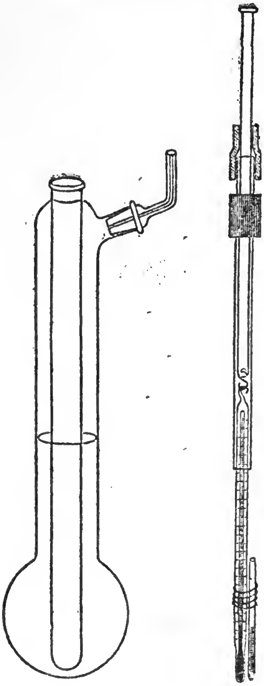


Fig. 8.

Regularities in Melting Points.—(1) In the case of isomers it has been observed that the member possessing the most symmetrical structure generally shows the highest melting point; for instance, among the aromatic series, para-compounds melt at a higher temperature than ortho- or meta-compounds. (2) Of the alkyl esters of the carboxylic acids those with the methyl residue have a higher melting point than that of the next homologues (see oxalic esters). (3) In homologous series with like linkages the melting point alternately rises and falls (see saturated normal aliphatic mono- and dicarboxylic acids, B. **29**, R. 411; C. 1900, I. 749). The members, having an uneven number of carbon atoms, have the lower melting points (*Baeyer*, B. **10**, 1286). This is also true of acid amides having from 6 to 14 carbon atoms (B. **27**, R. 551), and for the normal primary diamines (C. 1900, II. 1063; 1901, I. 610, etc.; Z. phys. Ch. **50**, 43). (4) In the case of the benzene nitro-compounds and their derivatives—the azoxy-, azo-, hydrazo-, and amido- bodies—as well as the corresponding diphenyl compounds, it has been observed that as oxygen is withdrawn the melting point rises until the azo-derivatives are reached, when it descends to the amido-bodies (*G. Schultz*, A. **207**, 362). To all these regularities among melting points there exist numerous exceptions (*Graham-Otto*, Lehrbuch der Chemie, Vol. I. part 3 (1898), p. 505; *Franchimont*, C. 1897, II. 256). For the melting points of mixtures, see B. **29**, R, 75.

4. BOILING POINT ; DISTILLATION

The boiling points of carbon derivatives, which are volatile without decomposition, are as important for the purpose of characterization as the melting points. In case of the latter the influence of pressure is so slight that it can be neglected, but the former vary very markedly when comparatively inappreciable changes in pressure occur. Hence in stating a boiling point accurately it is necessary to add the pressure at which it was observed. When the quantity of material is ample the boiling point is determined by distillation. For the determination of the boiling points of very small amounts of liquids, see B. **24**, 2251, 944; **19**, 795; **14**, 88.

Distillation under Ordinary Pressure.—For this purpose a special flask is employed, the long neck of which is provided with a side tube pointing downwards at an angle. The neck of the flask is closed with a stopper, bearing a thermometer. It must not be forgotten that very frequently the vapours of organic substances attack ordinary corks or those of rubber, therefore the exit tube should be placed a considerable distance from the end of the neck; or the neck may be narrowed at the upper end and the thermometer held in position by means of a piece of india-rubber tubing passed outside it. The mercury bulb of the thermometer should be slightly below the level of the exit tube in the neck of the flask. The latter should be at least one-half filled with the liquid to be distilled.

If the thermometer is not wholly immersed in the vapour, the external mercury column will not be heated to the same degree as that on the interior, hence the recorded temperature will be less than the true one. The necessary correction is the same as that which has already been given for the melting point. By using a shorter thermometer with a scale not exceeding 50°, which can be wholly surrounded by the vapour, the correction becomes unnecessary.

In general, when the boiling point "under ordinary pressure" is recorded, it is understood to mean at 760 mm. of mercury. If the barometric column does not indicate this amount during the distillation, a second correction is necessitated (B. **20,** 709; *Landolt-Boernstein,* Tabellen, 3rd edition, 1905, p. 177). To avoid this it is advisable to adjust the pressure in the apparatus to the normal, for which purpose the regulators of *Bunte* (A. **168,** 139) and *Lothar Meyer* (A. **165,** 303) are suitable.

*Distillation under Reduced Pressure.**—Attention has already been directed to the great variation in boiling points with variation in temperature. Many carbon derivatives whose decomposition temperature, at the ordinary pressure, is lower than that of their boiling points, can be boiled under reduced pressure at temperatures below the point at which they break down. Distillation under reduced pressure is often the only means of purifying liquids which decompose when boiled at the ordinary pressure, and which cannot be crystallized. This method is of primary importance in scientific research in the laboratory, and is rapidly being introduced into technical operations with much success.

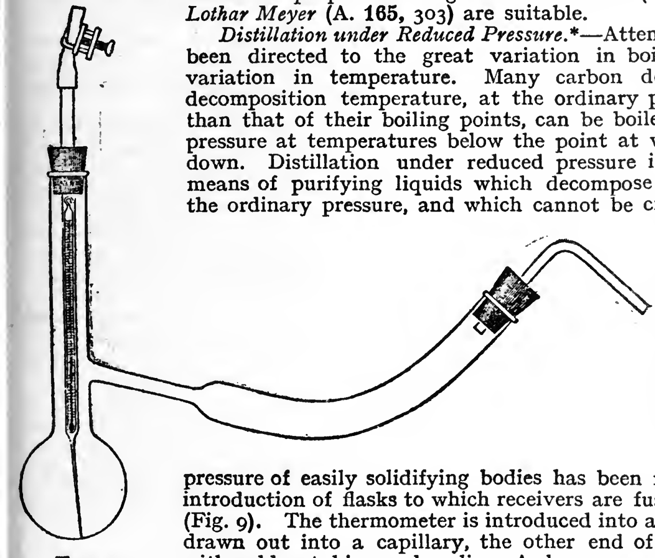


FIG. 9.

Distillation under reduced pressure of easily solidifying bodies has been facilitated by the introduction of flasks to which receivers are fused or ground in (Fig. 9). The thermometer is introduced into a thin-walled tube drawn out into a capillary, the other end of which is closed with rubber tubing and a clip. A slow current of gas is drawn through the liquid during distillation, and in this way bumping is avoided. The distillation flask is best heated in a bath. Usually the pressure is lowered by means of a water pump, but when it is desired to distil at pressures lying near the absolute vacuum, it will be found advantageous to use a Sprengel mercury pump, which is set into motion, according to *Babo's* method, by means of a water suction pump; compare *Kahlbaum* (B. **27,** 1386); *F. Krafft* and *H. Weilandt* (B. **29,** 1316); *Precht* (B. **29,** 1143).

A still simpler method of attaining very low pressures consists in the employment of liquid air. A vessel, containing very finely divided pure blood-charcoal, or cocoanut charcoal, is interposed between the apparatus illustrated in Fig. 9 and the air pump. On cooling it with liquid air the small amount of gas left in the apparatus condenses in the charcoal, and the pressure falls to a fraction

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* Compare *Anschütz* and *Reitter,* Die Destillation unter vermindertem Druck im Laboratorium, 2nd ed., 1895, Bonn. The tables in this book record the boiling points of over 400 inorganic and organic substances under reduced pressure. *George W. Kahlbaum,* Siedetemperatur und Druck, Leipzig, 1885. Dampfspannkraftsmessungen, Basel, 1893. *Meyer Wildermann,* Die Siedetemperaturen der Körper sind eine Funktion ihrer chemischen Natur (B. **23,** 1254, 1468). *W. Nernst* and *A. Hesse,* Siede- und Schmelzpunkte, Braunschweig, 1893.

of a millimetre. If the apparatus is filled beforehand with CO_2, the charcoal can be omitted (B. **38**, 4149).

For distillation under any pressure, the apparatus of *Staedel* (A. **195**, 218; B. **13**, 839), and *Schumann* (B. **18**, 2085), may be used. For mercury thermometers registering temperatures to 550°, see B. **26**, 1815; to 700°, B. **27**, 470.

Fractional Distillation.—Liquids having different boiling points can be separated from mixtures by *fractional distillation*—an operation that is performed in almost every distillation. Portions boiling between definite temperature intervals (from 1–10°, etc.) are collected separately and subjected to repeated distillation, those portions boiling alike being united. To attain a more rapid separation of the rising vapours, these should be passed through a vertical tube, in which the vapours of the higher boiling compound condense and flow back, as in the apparatus employed in the rectification of spirit or benzene. To this end there is placed on the boiling flask a so-called *fractionating column* of *Würtz*. Excellent modifications of this have been described by *Linnemann*, *Le Bel*, *Hempel*, *Young*, and others. For the action of these "heads," see A. **224**, 259; B. **18**, R. 101, and A. **247**, 3; B. **28**, R. 352, 938; **29**, R. 187. The action of these fractionating columns is increased if enclosed by a highly evacuated jacket (B. **39**, 893, footnote).

*Relation of Boiling Point to Constitution.**—(1) Generally the boiling point of members of a homologous series rises with the increasing number of carbon atoms. (2) Among isomeric compounds of equal carbon content, that possessing the more normal structure boils at a higher temperature. The addition of the methyl groups depresses the boiling point. It is noteworthy that the lowest boiling isomers possess the greatest specific volume (B. **15**, 2571). (3) Unsaturated compounds boil at a higher temperature than those which are saturated. (4) The substitution of a hydrogen atom by a hydroxyl group raises the boiling point about 100°.

The connection existing between the boiling points and chemical constitution of the compounds will be discussed later in the several homologous groups.

5. SOLUBILITY

The hydrocarbons and their halogen substitution products are either insoluble, or only very slightly soluble, in water. They dissolve, however, very readily in alcohol and in ether, in which most other carbon derivatives are also soluble.

Ether, but slightly miscible with water, is employed to extract many substances from their aqueous solutions, separating funnels being used for this purpose.

The more oxygen a compound contains, the more readily soluble is it in water; especially is this true when several of the oxygen atoms are combined with hydrogen, *i.e.* when hydroxyl groups are present in the organic compound.

The first members of homologous series of alcohols, aldehydes, ketones, and acids are soluble in water, but as the carbon content increases, the hydrocarbon character, in relation to solubility, becomes more and more evident, and the compounds become more and more insoluble in water.

In addition to water, alcohol, and ether, other solvents are employed as solvents, such as carbon disulphide, chloroform, carbon tetrachloride, methylal, acetone, glacial acetic acid, ethyl acetate, benzene, toluene, xylene, aniline, nitrobenzene, phenol, etc. Light petroleum spirit, derived from American petroleum, is especially valuable; it is composed of lower paraffins, and is often used to separate compounds from solvents with which it is miscible, because very many organic substances are insoluble or dissolve with difficulty in it.

The solubility of a compound is dependent upon the temperature, and is constant for a definite temperature. This means is frequently employed for purposes of identification.

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* On the connection between the boiling point and the chemical constitution of a substance, as known at present, see *Graham-Otto*, Lehrbuch der Chemie, Vol. I. part 3, p. 535 (1898); also *Menschutkin*, C. 1897, II. 1067.

For the regularities among the solubilities of isomeric carbon derivatives, consult *Carnelley*, Phil. Mag. [6] **13**, 180; *Carnelley* and *Thomson*, J. Ch. S. **53**, 801.

For apparatus suitable for determining solubility, see *V. Meyer*, B. **8**, 998, and *Köhler*, Z. anal. Ch. **18**, 239; B. **30**, 1752.

6. OPTICAL PROPERTIES

Colour.—Most organic compounds are colourless, many are coloured; *e.g.* iodoform is yellow, whilst carbon tetraiodide is dark red. The presence of certain atomic groups is connected with definite colours, particularly in the case of the aromatic derivatives. The nitro-bodies, for example, are more or less yellow, whilst the azo-derivatives vary from orange to red, etc. The colour of the solution of coloured substances depends to a large extent on the nature of the solvent (B. **27**, R. 20; **39**, 4153).

Dye-stuffs.—Many coloured compounds, belonging almost exclusively to the aromatic series, possess the property of dyeing vegetable or animal fibres, either directly or through the agency of mordants.

According to *O. N. Witt*, an aromatic substance behaves as a dye when it includes a *chromophoric* group, *e.g.* NO_2, N_2, etc., as well as an *auxochrome* group, such as an OH or amino-group, in its composition. The latter occupy the ortho- or para- position to the chromophor. A substance containing a chromophoric group alone is called a *chromogen* (B. **9**, 522; **35**, 4225; **36**, 3008).

Fluorescence.—This property, like that of colour, results from the presence in the molecule of certain *fluorophoric* groups (*R. Meyer*, B. **31**, 510; C. 1900, II. 308; Chem. Ztg. **29**, 1027).

Refraction.—The carbon compounds (like all transparent substances) possess the power of refracting light to a varying degree.

The *coefficient of refraction* or *refractive index* (n) for homogeneous light passing from medium 1 into medium 2, represents the ratio of the velocities of propagation v_1 and v_2 in both media; $n=\frac{v_1}{v_2}$. For single refracting media, in which similar optical behaviour is observed in all directions (a condition which is seldom found in crystals) n is independent of the direction of the incident light, so that if i and r are the incident and refractive angles $n=\frac{v_1}{v_2}=\frac{\sin i}{\sin r}$, a constant number for light of a definite wave-length.

Specific Refractive Power.—The refractive index (n) varies with the temperature, consequently also with the specific gravity of the liquid.

Their relation to each other is approximately expressed by the equation;

$$\frac{n-1}{d}=\text{const.} \qquad \text{or} \qquad \frac{n^2-1}{n^2+2}\cdot\frac{1}{d}=\text{const.}^*$$

(Gladstone's formula). n-formula. (Lorenz and Lorentz's formula). n^2-formula.

where d is the sp. gr. of the liquid, determined at the same temperature as the refractive index. The constant remains practically unchanged for any temperature.

Molecular Refractive Power or *Molecular Refraction* is the specific refractive

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* See *Graham-Otto*, Lehrbuch der Chemie, Vol. I. part 3, p. 567, 1898.

power of a substance multiplied by its molecular weight. It is represented by M or $\mathfrak{M}$, according to whether *Gladstone's* or the n^2 formula is adopted:

$$M = \frac{n - 1}{d} \cdot p. \qquad \mathfrak{M} = \frac{n^2 - 1}{n^2 + 2} \cdot \frac{n}{d} \cdot p.$$

It is immaterial which of the two formulæ is employed in the examination of stoichiometrical questions, so long as fluid substances are referred to. In a comparison of liquids with their vapours the n^9 formula only can be used, and it is also to be preferred when dealing with aromatic substances.

The molecular refraction of a liquid carbon compound is equal to the sum of the atomic refractions r, r′, r″:

$$M = ar + br' + cr'',$$

in which *a*, *b*, *c*, represent the number of elementary atoms in the compound. The atomic refractions of the elements are deduced from the molecular refractions of the compounds obtained empirically, in the same manner as the atomic volumes are obtained from the molecular volumes. Whilst it was formerly assumed that but *one* atomic refraction existed for each element in its compounds, later researches have proved that only the univalent elements have a constant atomic refraction, and that of the polyvalent elements, *e.g.* oxygen, sulphur, carbon, is influenced by their manner of union.

This is seen in the rise in the molecular refraction by a constant quantity, amounting to 2·4 for the *n*-formula, and 1·84 in the case of the n^2-formula, for each double bond of a carbon atom. A treble bond possesses the n^2 value of approximately 2·2.

The refraction is determined either for the yellow sodium line (the D line in the solar spectrum), or for the red hydrogen line H*a* (C in the solar spectrum). These values are affected by the disturbing influence of "*dispersion*," and a refractive index free from this factor has not yet been developed (see Dielectric Constant, p. 53). The molecular refraction ascertained by means of the above formula from the *observed* values of the refraction and density, can be compared with that calculated by the addition of the particular atomic refractions, as given in the accompanying table.

—	—	Gladstone's formula.		Lorenz's formula.	
		r_a	r_D	r_a	r_D
Carbon (single bond)	C′	5·00	4·71	2·365	2·501
Hydrogen	H	1·30	1·47	1·103	1·051
Oxygen (in hydroxyl)	O′	2·80	2·65	1·506	1·521
Oxygen (in ethers)	O<			1·655	1·683
Oxygen (carbonyl)	O″	3·40	3·33	2·328	2·287
Chlorine	Cl	9·79	10·05	6·014	5·998
Bromine	Br	15·34	15·34	8·863	8·927
Iodine	I	24·87	25·01	13·808	14·12
Ethylene linkage	=	2·4	2·64	1·836	1·71
Acetylene linkage	≡	—	—	2·22	—

The atomic refraction of nitrogen in its various combinations has been minutely investigated by *Brühl*, but final results have not, as yet, been attained.

It is, therefore, obvious that important data relating to the manner of union of the atoms in the molecule of a carbon compound can be obtained from the molecular refractions. When the observed molecular refraction is in excess of the calculated value, the presence of a double or treble bond is indicated. Thus the greater molecular refraction (by 3 × 1·78 = 5·34 units) of the benzene bodies, confirms the view, previously deduced from chemical facts, that there are present in the benzene nucleus three doubly-linked carbon atoms. Among the terpenes the change from a ring formation to an open chain with a double bond can be followed (B. **20,** 2288; **22,** 2736; **23,** 855; **24,** 656, 2450; **25,** 2638). In many cases among the substances referred to by *Laar* as being tautomeric, it has been possible to ascertain whether they exist in the enol- or keto- form (B. **25,** 366, 3078; **38,** 1868). However, the regularities noted above only hold good for bodies with slight dispersive power, such as the fatty bodies. In the case of substances possessing a greater dispersive power than cinnamyl alcohol, the molecular refraction is valueless for the determination of chemical structure (B. **19,** 2746; **24,** 1823).

On the employment, for the elucidation of stoichiometrical problems, of the *molecular dispersion* of bodies, *i.e.* the difference between the refractions measured with blue and red hydrogen lines, see *Brühl* (Z. phys. Ch. **7,** 140).

The *refraction stere* of *J. Traube* is the quotient obtained by the division of the molecular refraction by the number of atomic valencies. Within certain limits it approximates to a constant (0·787) which is of special significance in the theory of valency (B. **40,** 130, 723).

The *Abbé total refractometer,* and *Pulfrich's total reflectometer* are much more convenient than the spectrometer for rapid and sufficiently accurate working (Z. phys. Ch. **18,** 294; B. **24,** 286).

Dielectric Constant.—The electrostatic force by which two electrified bodies affect one another varies with the nature of the insulating "dielectric medium" which separates them. Taking air as unity, the measurement made with another substance under similar circumstances gives the *dielectric constant* of that medium. This value, usually indicated by κ, has been taken for a large number of carbon compounds;* for example:—

	κ		κ
Gases and Vapours, about .	1·0	Fatty Acids, about .	2·6–7·0
Liquid Hydrocarbons .	2·0–2·5	Fatty Acid Esters .	5–9
Carbon Disulphide . . .	2·6	Fatty Alcohols . .	16–35
Ethyl Ether	4·5	Water	80

The electromagnetic theory of light is based on the fundamental principle that light and electromagnetic waves are of the same nature, differing from one another only in length. The refractive index, for an infinitely long wave can be closely connected to the dielectric constant, by the relation $\sqrt{\kappa} = n\alpha$. The determination of the dielectric constant thus supplies directly a value for the refractive index free from dispersion, analogous to the Lorenz formula (p. 51).

$$P \cdot \frac{\kappa - 1}{\kappa + 2} \cdot \frac{1}{d} = \text{const.}$$

The values obtained in investigations so far carried out † have not led in general to a good correspondence with those derived by optical methods, whilst the optical molecular refraction measurements show an additive character (at least for compounds of similar constitution), the values obtained by electrical methods are influenced by insignificant differences in constitution of each substance. In this case there is no possibility of calculating "atomic refractions,"

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* On the method of measurement for chemical purposes, see *Nernst* (Z. phys. Ch. **14,** 622; **24,** 21); *Wied* (A. **57,** 215; **60,** 600); *Drude* (Z. phys. Ch. **23,** 267).

† *Landolt* and *Jahn* (Z. phys. Ch. **10,** 289). See also *Graham-Otto,* Lehrb. der Chemie, I. part 3, p. 650, 1888.

but rather to trace and disclose differences in constitution by electrical means, for which purpose it is of great assistance. Under certain circumstances the attendant phenomenon of *anomalous electrical absorption* is to be observed, *i.e.* the partial change of electrical into heat energy. Almost all the non-conducting carbon compounds which give rise to this absorption contain the hydroxyl group. On this observation is based a method of detecting and demonstrating the mutual change of keto- and enol-forms (*Drude*, B. **30**, 940; Z. phys. Ch. **23**, 308, 318). Further progress in this investigation will doubtless yield important results.

The vapours of many groups of aliphatic and specially aromatic bodies absorb *Tesla currents* at ordinary pressure and change them into light waves. Such substances, for example, are the primary aromatic amines, and the simple aliphatic aldehydes and ketones. In the latter case the keto-group seems to be the vehicle of the luminescence, at any rate neither the vapours of paraldehyde nor of acetaldehyde become illuminated (*H. Kauffmann*, B. **35**, 473).

Optical Rotatory Power,* Rotation of the Plane of Polarization by Liquid or Dissolved Carbon Compounds.—*Biot*, in 1815, observed that many naturally occurring bodies such as the sugars, the terpenes, and camphors, were capable of rotating the plane of polarized light. He also showed, in 1817, how the vapours of turpentine also deviated the plane of polarization, and concluded that this power was a property of chemical molecules. Such bodies are termed ***optically active carbon compounds.***

Specific Rotatory Power $[\alpha]$.—The angle of rotation α is proportional to the length l of the rotating column (usually expressed in decimetres); hence the expression $\frac{\alpha}{l}$ is a constant quantity. To compare substances of different density, in which very unequal masses may be contained in this column, they must be referred to a like density, and hence the rotation must be divided by the sp. gr. of the substance at a definite temperature. The expression

$$[\alpha]_D \text{ or } [\alpha]_j = \frac{\alpha}{ld}$$

is called the *specific rotatory power* and is designated by $[\alpha]_D$ or $[\alpha]_j$, according as the rotation is referred to the yellow sodium line D or the "transitional colour" j. For solid, active substances, in an indifferent solvent, the equation employed is

$$[\alpha] = \frac{100\alpha}{pld},$$

where p represents the quantity of substance in 100 parts by weight of the solution, and d represents the specific gravity of the latter.

This specific rotatory power is constant for every substance at a definite temperature; it varies, however, with the latter, and, in the case of solutions, with the nature and quantity of the solvent. So much is this the case, that under various conditions the angle of rotation for one and the same substance can become zero or even change in sign. Therefore, in the statement of the specific rotatory power of dissolved substances the temperature and percentage strength of the solution are always given.

In many cases the addition of substances such as salts, etc., causes a change in the rotation. Such active bodies, including tartaric acid, malic acid, mandelic acid, and others, which contain an alcoholic hydroxyl group, are powerfully influenced by the addition of alkali borates, molybdates, tungstates, and uranates. The phenomenon depends apparently on the formation of complex combinations (B. **38**, 3874, etc.), and can sometimes be used to increase the rotation of active substances, of which the rotatory power would otherwise be too small to be measured alone, either on account of specific value being insignificant or because the solution employed is too weak. (See *Landolt*, previous reference, footnote, p. 220; *Walden* (B. **30**, 2889).)

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* *Landolt*, Das optische Drehungsverm gen organischer Substanzen und die practische Andwendung derselben, 2nd edition, Braunschweig, 1898. *Walden*, Ueber das Drehungsvermögen optisch aktiver Körper, B. **38**, 345.

Molecular Rotatory Power is the product of the specific rotatory power [α] and the molecular weight P. As these values are usually high, the molecular weight is divided by 100.

$$[M] = \frac{P \cdot [\alpha]}{100}.$$

The most suitable apparatus for measuring rotation are described in the abovementioned work of *Landolt* (p. 54, footnote).

In 1848 *Pasteur* demonstrated that in optically active substances, such as tartaric acid and its salts, the rotatory power is intimately connected with the crystalline form, and is usually connected with the presence of hemihedral faces. In the discussion of the stereochemical or spacial theories, reference was made to the fact that *Pasteur* considered the asymmetric structure of the molecules of optically active carbon compounds to be the cause of their remarkable action upon polarized light.

According to the theory of *van 't Hoff* and *Le Bel*, the activity of the carbon compounds is dependent upon the presence of *asymmetric* carbon atoms or on the asymmetric arrangement of atoms attached to a carbon skeleton in space (p. 30).

So far as they have been investigated, all optically active carbon compounds contain one or more asymmetric carbon atoms. However, there are many compounds containing such atoms, which, when they exist as liquids, or when in solution, have no effect upon polarized light. This is true when two molecules of opposite but equal rotatory power unite to form a molecule of a physical, polymeric compound, *e.g.* inactive lactic acid, inactive malic acid, inactive asparagine, inactive aspartic acid, racemic acid, etc.; also, when the half of a molecule neutralizes the rotation produced by the other half, as in mesotartaric acid.

It has also been shown that in the conversion of optically active bodies into their derivatives the activity continues so long as the latter contain asymmetric carbon atoms; when the asymmetry disappears, the derivatives become inactive. The two active tartaric acids yield two active malic acids; active asparagine yields active aspartic acid, active malic acid, etc., whilst the symmetrical succinic acid that is obtained by further reduction is inactive.

If various groups, each containing an asymmetric carbon atom, be introduced into a molecule, the final rotation will be the algebraic sum of the rotations of the single groups: see especially, *Guye* (C.r. **119**, 953; **120**, 632; **121**, 827; **122**, 932); and *Walden* (Z. phys. Ch. **17**, 721).

By changing or substituting a single group or element, connected with an asymmetric C atom, the rotatory power is often very considerably influenced; as, for instance, by the production of an ethylenic linkage or by ring-formation (C. 1903, II. 116; 1905, II. 31; A. **327**, 157); or when alkyl groups are introduced into NH or OH groups (B. **34**, 2420; C. 1905, II. 455). In the case of malic acid the optical antipodes can be transformed into one another by a continuous series of changes; l-malic ester, with PCl_5, gives d-chlorosuccinic ester, the acid of which with silver oxide yields d-malic acid. Conversely, d-malic ester, with PCl_5, gives l-chlorosuccinic ester, of which the acid can be converted into l-malic acid. Similarly, l-bromo- or l-chlorosuccinic acid, acted on by ammonia in methyl alcohol solution, yields d-aminosuccinic acid, which is changed into d-malic acid by barium hydroxide. Finally, the halogen substitution products of the active succinic acids, when acted on by potassium hydroxide instead of silver oxide, have their halogens replaced by hydroxyl to form the hydroxy-acids, possessing *not* the *same* but the *opposite* direction of rotation (*Walden*, B. **30**, 3146). Similar " reversed rotations " can be observed among the simple amino-acids, such as alanine and leucine (*q.v.*) (B. **39**, 2895; **40**, 1051).

Asymmetric compounds prepared in the laboratory from inactive substances are inactive. This results from the simultaneous formation in equal quantities of the two optical antipodes which manifest a tendency to combine to form the inactive, physically polymeric molecules. *Asymmetric syntheses*, *i.e.* the preparation of one active body from an inactive one without the intermediate formation of a racemic body, can, however, sometimes be effected, by combining the inactive compound with an active one and then carrying out the change which will produce the active substance sought: methyl ethyl malonic acid combines with the active alkaloid brucine forming an acid salt. On heating, CO_2 escapes, and when the resulting brucine methyl acetyl acetate is decomposed with hydrochloric acid, optically active methyl ethyl acetic acid is obtained (B. **37,** 1368; C. 1906, I. 1613; II. 53).

Racemic Bodies.—The typical substance, racemic acid, has given its name to all similar inactive mixtures of the two optical antipodes. The racemic substance differs from its components also in that it forms crystals which do not give rise to enantiomorphic modifications. The density of the racemic body is, as a rule, greater and its solubility less than the corresponding active substances, but not always; similarly there is no general rule for the relative position of the melting point.

When the crystalline form of an inactive substance cannot be observed with accuracy, as often happens, and when at the same time, the melting point lies lower than that of either of the optically active components, then doubt may arise whether it is a true racemate or a mixture of equal quantities of the optical antipodes. A variety of tests can be applied. The melting point may be taken after a small quantity of one of the active components has been added to the inactive substance. The composition may be determined, as well as the optical behaviour, of a concentrated solution of the inactive body as compared with that of a mixture of the inactive and one active substance. If the addition of the active body causes a lowering of the melting point of the inactive substance, a change in the concentration and in the optical activity of the saturated solution, then the substance is a racemic one; if, on the other hand, the melting point rises, and the concentration and inactivity of the solution are unaltered, then the inactive body is a mixture.

The formation of a racemic substance is dependent on the temperature. Above or below its *transformation temperature* the body may be a racemic body or an enantiomorphic mixture. The results of the above experiments hold good, then, only for the particular temperature at which they are carried out, and a series of experiments over a wide range of temperature is necessary to obtain a complete insight into the matter.

These practical tests are, in part, the direct result of the considerations on heterogeneous equilibrium as put forward in *Gibb's phase rule* (*van 't Hoff*, B. **31,** 528; *Ladenburg*, B. **32,** 1822; *Roozeboom*, Z. phys. Ch. **28,** 494, etc. Also B. **33,** 1082).

Pseudo-racemic mixed crystals, although inactive, possess the form of the active modifications, without, however, the hemihedric faces (J. Ch. S. **71,** 889; **75,** 42).

Resolution of Inactive Carbon Compounds into their Optically Active Components.—The synthesis of optically active carbon compounds is easily realized by direct methods, because it is possible to separate the dextro- and lævo-rotatory components in an inactive molecule. The following methods, 1, 2, and 5, were employed by *Pasteur* (1848) in his study of the racemates and racemic acid. This classic investigation supplies the firm experimental basis for the theory of *stereochemistry* or the *space chemistry* of carbon (p. 29).

Method 1, *based upon resolution by crystallization.*—The substance itself, or its derivatives with optically inactive compounds, is crystallized at varying temperatures and from various solvents. In the case under consideration it is possible to separate two substances showing enantiomorphous hemihedrism by actually picking out those crystals exhibiting the particular forms. Thus, from a solution of sodium ammonium racemate below 28° hemihedral crystals of sodium ammonium dextro- and lævo-tartrates can be obtained (B. **19,** 2148).

Method 2, *dependent upon the formation of compounds with optically active substances.*—*Pasteur* succeeded in separating d- and l-tartaric acids through their quinicine and cinchonine salts. This was because these, being no longer enantiomorphous, were distinguished by their varying solubility, and so could be very easily separated from each other.

Ladenburg first used the latter method to resolve *inactive bases* by forming salts of the latter with an active acid. It was thus that he decomposed synthetic inactive coniine (α-n-propyl piperidine) by means of dextro-tartaric acid into its active components, and completed the synthesis of the first optically active vegetable alkaloid—coniine—which occurs in hemlock (*q.v.*).

The resolution of racemic substances does not always immediately result from the combination with active bodies and the subsequent precipitation of the more insoluble of the new compounds. Under certain conditions the racemic body unites, as such, with the added active body, forming a *semi-racemic* compound (such as strychnine racemate), which can only be decomposed into compounds of its active components at a particular temperature (*Ladenburg*, B. **31**, 1969; **32**, 50).

Method 3, *based on the formation of esters or amides* between *racemic* and *optically active substances.*—Racemic mandelic acid can be partially turned into the l-menthol ester, whereby the residue consists of an excess of l-mandelic acid. If l-quinic acid be heated with rac. α-phenyl ethylamine, the dextro-rotatory acid, which does not take part in the amide formations, remains behind (B. **38**, 801).

Method 4.—Enzymes, such as maltase or emulsin, decompose racemic glucosides (*E. Fischer*, B. **28**, 1429).

Method 5.—On introducing some suitable fungus such as *Penicillium glaucum* into an aqueous solution of an inactive mixture, capable of resolution, one modification of the mixture will be destroyed during the life-process of the fungus; thus *racemic acid* yields *l-tartaric acid*, *inactive amyl alcohol* yields d-*amyl alcohol*, *methyl propyl carbinol* yields l-*methyl propyl carbinol*, *propylene glycol* yields l-*propylene glycol*, etc.

One fungus may leave an optical modification untouched which another may destroy.

Penicillium glaucum or *Bacterium termo* will leave d-mandelic acid from the synthetic inactive racemic acid, whilst *Saccharomyces ellipsoideus* or *Schizomycetes* leave the l-acid untouched. For the literature of the resolution of racemic compounds, see *Landolt*, Optisches Drehungsvermögen, etc., 2nd edition, p. 86, 1888.

Carbon compounds, in which an asymmetric carbon atom is not present, could *not* be decomposed by these methods (A. **239**, 164; B. **18**, 1394).

Conversion of Optically Active Substances into their Optically Inactive Modifications.—Whilst soluble salts of optically inactive, resolvable carbon compounds may be resolved by crystallization under proper conditions of temperature, many others reunite to form a salt of the inactive body, especially if the latter dissolves with difficulty. Solutions of lævo- and dextro-tartrate of calcium when mixed yield a precipitate of calcium tartrate, which dissolves with difficulty. The free, optically active modifications unite, as a rule, very easily when mixed in solution, to form the inactive decomposable modification, *e.g.* lævo- and dextro-tartaric acid yield racemic acid. The esters of these acids behave in a similar manner: lævo- and dextro-tartaric methyl esters unite directly and in solution to form racemic methyl ester (B. **18**, 1397). Also, in energetic reactions, or when heated, the active varieties rapidly pass into the inactive forms, *e.g.* dextro-tartaric at 175° yields racemic acid, and at 165° mesotartaric acid. At 180° dextro- and lævo-mandelic acids pass into inactive mandelic acid. Some optically active halogen substitution products of carboxylic acids undergo auto-racemation, even at ordinary temperatures (B. **31**, 1416).

A corresponding behaviour is observed in the decomposition of albumins, when heated with barium hydroxide, into inactive leucine, tyrosine, and glutamine, whilst at a lower temperature hydrochloric acid produces the active modifications (B. **18**, 388). For an experimental explanation of the transformation of optically active substances into their inactive modifications, compare *A. Werner* in R. Meyer's Jahrbuch der Chemie **1**, 130.

Magnetic Rotatory Power.*—*Faraday*, in 1846, discovered that transparent, isotropic, optically inactive bodies were capable of rotating the plane of polarized light when a column of the substance was brought into the magnetic field, as, for example, when it was surrounded by an electric current. The power of rotation only continued as long as these influences were active, and was reversed when the position of the magnetic poles were reversed; this distinguished magnetic rotatory power from the rotatory power of optically active carbon compounds.

Specific magnetic rotatory power is the degree of rotation that the plane of polarization of a ray of light undergoes when it passes through a layer of liquid of definite thickness, exposed to the influence of a magnet. The unit of comparison is the rotation produced by a layer of water of the same temperature and thickness when exposed to the same magnetic field.

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* *Graham-Otto*, Lehrbuch der Chemie, Vol. I. part 3, p. 793, 1898.

Molecular Magnetic Rotatory Power.—This is the degree of rotation produced by columns of liquids chosen of such a length that similar cross-sections will each contain a molecular weight of the substance. The unit in this case can also be the molecular rotatory power of water.

W. H. Perkin, Sr., has investigated minutely the connection between the magnetic rotatory power and the constitution of carbon derivatives. Numerical relations between the increase of rotation and change of composition have been established for many groups of aliphatic and aromatic compounds (C. 1900, I. 797; 1902, I. 621). Deviations from the theoretical values are encountered particularly in the reactive benzene substitution compounds (see Table, J. pr Ch. [2] **67**, 334).

7. ELECTRIC CONDUCTIVITY

Substances which are capable of conducting electricity arrange themselves into two groups: *conductors of the first class*, or those which conduct electricity without undergoing any change, and *conductors of the second class*, known as *electrolytes*, in which conduction is only possible through the agency of the *ions* in which the solutes separate when dissolved. The greater the conductivity of a substance the less is the resistance to the passage of the current; in other words, the resistance is inversely proportional to the conductivity. The unit of measurement of resistance is the ohm—the resistance of a column of mercury 1·06 metres long, and 1 mm. in cross section, at 0° C.

Ostwald's investigations have demonstrated that the conductivity of electrolytes is intimately related to chemical affinity, and forms a direct measure of the chemical affinity of acids and bases. Therefore, the determination of the conductivity of electrolytes (in aqueous solution), to which all organic acids and their salts belong, is of great interest and importance for all carbon derivatives.

Kohlrausch (*Wied*, A. **6**, 1) has suggested a very simple and accurate means of determining the conductivity of electrolytes, which has been extensively applied by *Ostwald* (J. pr. Ch. **32**, 300, and **33**, 352; Z. phys. Ch. **2**, 561). (See also C. 1900, I. 577.) It is dependent on the application of alternating currents, produced by an induction coil, so that the disturbing influence of galvanic polarization is avoided.

The conductivity of electrolytes is not referred to the percentage content of their aqueous solutions, but (as the conductivity is determined by the equivalent ions) to solutions containing a gram-molecule, or a gram-equivalent of substance in one litre. This value is the *molecular* (or equivalent) *conductivity* of the substance (Z. phys. Ch. **2**, 567).

F. Kohlrausch and *Holborn*, in their book, "Das Leitungsvermögen der Elektrolyte," refer the conductivity of a solution to a unit consisting of a column 1 cm. long, and 1 cm.^{2} in section which has a resistance of 1 ohm. In this case the conductivity becomes 10,600 times as great as the above. Also, they employ the gram-equivalent in place of the gram-molecule, and the cubic centimetre in place of the litre.

The strong acids have the greatest molecular conductivity, and are followed by the fixed alkalies and alkali salts. Most organic acids, on the contrary (*e.g.* acetic acid), are poor conductors in a free condition, whilst their alkali salts approach those of the strong acids in conductivity. The *molecular* conductivity increases by about 2 per cent. per degree rise of temperature. It also increases with increasing dilution, and in the case of the poor conductors it is far more rapid than with the good conductors; in both instances it ultimately approaches a maximum (limiting) value. With good conductors this is attained at a dilution of about 1000 litres to the gram-molecule; whilst with those poor in conducting power it is only reached when the dilution is indefinitely large. In fact, in such cases the conductivity is practically indeterminable.

An interesting observation in connection with the alkali salts of all acids is the variable increase of the molecular conductivity with increasing dilution. This is true both in the case of the strong and the weak acids (most organic acids belong to the latter class), and it varies according to their basicity. With sodium salts of monobasic acids, this increase equals from 10–13 units, by dilution of 32–1024 litres for the equivalent of substance; for the salts of dibasic acids from 20–25 units, for those of the tribasic 28–31, for those of the tetrabasic about 40, and those of the pentabasic about 50 units.

Thus it may be seen that the increase in conductivity of acids, in the form of their sodium salts, offers a means of determining the basicity and, consequently, the molecular magnitude of acids (*Ostwald*, Z. phys. Ch. **1**, 74, 97; **2**, 901; *Walden*, *ibid.*, **1**, 530; **2**, 49).

If a certain quantity of an acid be neutralized with N/32 sodium hydroxide solution, and the conductivity of the neutral salt be measured before and after dilution to 32 times its volume, the difference of the conductivities divided by 10 gives the basicity of the acid.

Molecular conductivity has acquired still greater importance by its application to the measurement of the dissociation of the electrolytes; it is at the same time the measure of the reactivity or chemical affinity, first, of acids, then bases, and, finally, of salts.

Arrhenius's electrolytic dissociation theory maintains that in aqueous solution the electrolytes are more or less separated into their ions; this would give a simple explanation for the variations of solutions from the general laws of osmotic pressure, the depression of the freezing point, etc. (see p. 16). The dissociation is also manifest in the molecular conductivity, for the latter is directly proportional to the degree of dissociation, the number of free ions and the speed of migration of the free ions.

Molecular conductivity increases with dilution and dissociation. When the latter is complete, it attains its maximum (μ_∞). The degree of dissociation (m) (or the fraction of the electrolyte split up into ions) for any dilution is found from the ratio of the molecular conductivity at this dilution (μ) to the maximum conductivity (for an indefinite dilution):

$$m = \frac{\mu}{\mu_\infty}.$$

The latter (μ_∞) cannot be directly measured in the case of free organic acids, because most of them are poor conductors. But it can be obtained from the molecular conductivity of their sodium salts, by deducting from their maximum values the speed of migration of the sodium-ions (49·2), and adding those of the hydrogen-ions (352).

Since the molecular conductivity depends upon the dissociation of the electrolytes into their ions, the effect of dilution must follow the same laws as those prevailing in the dissociation of gases. This influence of dilution or volume (v) upon the molecular conductivity, or the degree of dissociation (m) is, therefore, expressed in the equation:

$$\frac{m^2}{v(1-m)} = \text{K},$$

which represents the law of dilution advanced by *Ostwald* (Z. phys. Ch. **2**, 36, 270).

This law has been fully confirmed by the perfect agreement of the calculated and observed values (*van 't Hoff*, Z. phys. Ch. **2**, 777). In the case of strong electrolytes, such as strong acids and bases, and most salts, the equation of *Rudolphi* is preferable to that of *Ostwald*, even though it is empirical: $\frac{m^3}{v(1-m)^2} = K$.

The value, K, is the same at all dilutions for every monobasic acid; hence it is a characteristic value for each acid, and is the measure of its chemical affinity. The determination of these chemical affinity-constants by *Ostwald* for more than 240 acids, has proved that they are closely related to the structure and constitution of the bodies (Z. phys. Ch. **3**, 170, 241, 369). Literature: see *Walden* (Z. phys. Ch. **8**, 833). Affinity values of stereoisomeric compounds: *Hantzsch* and *Miolatti* (B. **25**, R. 844).

Addendum: Determination of *affinity-coefficients:* *Conrad, Hecht,* and *Brückner* (Z. phys. Ch. **3**, 450; **4**, 273, 631; **5**, 289). *Lellmann* (B. **22**, 2101; A. **260**, 269; **263**, 286; **270**, 204, 208; **274**, 121, 141, 156). *Nernst* (R. Meyer's Jahrbuch **2**, 31).

HEAT OF COMBUSTION OF CARBON COMPOUNDS*

"The quantity of heat evolved in any chemical change is a measure of the total work, both physical and chemical, expended." The determination of the quantity of heat developed in complete combustion is alone adapted for the determination of the energy content of carbon compounds.

The heat of combustion of a carbon compound by the method of *Berthelot* is determined by combustion with oxygen at a pressure of 25 atmospheres in a calorimetric bomb, lined internally with platinum or enamel. Ignition is effected by means of an electric spark, or by the incandescent products of combustion formed by a thin iron wire heated electrically.

The method is so accurate that it can be employed for the detection of quite small quantities of impurity in an organic compound, the heat of combustion of which is known (J. pr. Ch. [2] **48**, 452; Z. f. angew. Ch., 1896, p. 486).

On the basis of the *Hess-Berthelot* principle: "The difference of the heats of combustion of two chemically equivalent systems is equal to the heat development which corresponds to the passage of the one system into the other": it is possible, knowing the heat of combustion of a carbon compound to calculate its heat of formation. The heat of combustion of the compound is deducted from the sum of the heats of combustion of its elements.

The heat of combustion of methane equals 211·9 cal.
" " diamond-carbon is 94 cal., and
" " hydrogen equals 69 cal.

As the complete combustion of methane proceeds according to the equation:

$$CH_4 + 2O_2 = CO_2 + 2H_2O,$$

then the heat of formation of this hydrocarbon, at constant pressure, would be 20·1 cal.:

$$94 + (2 \times 69) - 211{\cdot}9 = 20{\cdot}1.$$

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* Praktische Anleitung zur Ausführung thermochemischer Messungen, *Berthelot*, translated into German by *Siebert*, 1893. Grundriss der allg. Thermochemie, *Plank*, 1893. Die Grundsätze der Thermochemie und ihre Bedeutung für die theoretische Chemie, *Hans Jahn*, 2. Aufl. 1892. Grundriss der allg. Chemie, *Ostwald*, 1889. Mecanique chimique, *Berthelot*, Paris, 1879.

The development of methods for the determination of the heats of combustion is due to the investigations of *Favre* and *Silbermann*, *Thomsen*, *Stohmann*, and particularly of *Berthelot*. *Stohmann* especially determined the heat of combustion of numerous carbon derivatives, and published a tabulated account of the heats of combustion of organic bodies, made from 1852–1892 (Z. phys. Ch. **6**, 334; **10**, 410).

The regularities thus far observed are as follows: With the hydrocarbons of the paraffin and olefine series the constant difference of CH_2 in composition corresponds to a constant difference of 158 cal. in the heat of combustion. Similar relations occur in other homologous series.

The heat of combustion of the two isomeric propyl alcohols is almost the same, consequently in the case of similar linkage-relations position-isomerism is without influence upon the heat of formation and the heat of combustion. The difference of 6 cal. in the heats of combustion of fumaric acid (320·1 cal.) and maleïc acid (326·3 cal.) is more striking if we grant similar linkage-relations in the two acids, as is done by those who consider the difference between these two acids to be solely a stereochemical one.

The passage from a double linkage to two single linkages, as well as from a triple union to three simple unions is accompanied by considerable loss in energy. The relation of the heats of combustion of aromatic substances to their hydride derivatives is noteworthy. The differences of the heats of combustion of the dihydrobenzenes and their corresponding unaltered benzenes is considerably greater than the difference of the heats of combustion of the corresponding tetrahydro- and dihydro-benzenes. It is to be noticed that there appears to exist a quite small thermal difference between the olefine carboxylic acids and the tetramethylene dicarboxylic acids, as, for example, acrylic and tetramethylene dicarboxylic acids, cinnamic and truxillic acids (Z. phys. Ch. **48**, 345), as is also the case of the hexahydro- and tetrahydro-benzene derivatives. As to the contradictory conclusions which have been deduced from these facts in regard to the manner of union of the carbon atoms in the benzene ring, see A. **278**, 115; B. **27**, 1065; J. pr. Ch. [2] **48**, 452; **49**, 453.

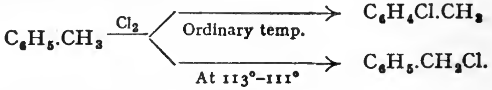
The varying stability of the tri-, tetra-, and penta-methylene rings referred by *Baeyer* to the varying ring-pressure (see the introduction to the carbocyclic compounds) is indicated in the heats of combustion, whilst no difference could be detected between the penta- and hexa-methylene rings. As an example as to how far observations upon the mentioned carbocyclic compounds can be applied to deductions upon constitution, it may be cited that the heat of combustion of camphoric acid excludes the assumption of a tri- or tetra-methylene ring, but indicates the likelihood of the presence of a penta- or hexa-methylene ring in camphor (J. pr. Ch. [2] **45**, 475; A. **292**, 125).

ACTION OF HEAT, LIGHT, AND ELECTRICITY UPON CARBON COMPOUNDS

I. ACTION OF HEAT

Substances which react most energetically upon each other do not do so at very low temperatures (*Raoul Pictet*, Arch. d. Scienc. phys. et nat., Geneva, 1893), even when subjected to the greatest pressure, and when their molecules are in most intimate contact. A definite temperature is essential for the occurrence of chemical action. The energy of a reaction, the time within which it proceeds, is largely dependent on the temperature of the reacting substances, therefore the determination of the most favourable temperature for the reaction is important. It must be remembered that the heat developed in chemical changes frequently increases the initial reaction-temperature rapidly to the point of decomposition. In such cases the violence of the reaction must be moderated by cooling or by the use of indifferent diluents, in which the substances acting upon each other must be dissolved before the reaction occurs.

The action of chlorine upon toluene (*q.v.*) or upon methyl toluene shows particularly well how much the kind and nature of the action is dependent upon the temperature. At the ordinary temperature the chlorine substitutes the hydrogen of the phenyl residue, whilst at the boiling temperature it is the hydrogen of the methyl group which is replaced :



$$C_6H_5.CH_3 \xrightarrow{Cl_2} \begin{cases} \xrightarrow{\text{Ordinary temp.}} C_6H_4Cl.CH_3 \\ \xrightarrow[\text{At } 113°–111°]{} C_6H_5.CH_2Cl. \end{cases}$$

Numerous analogous observations are known.

In general, carbon compounds are much less stable under the influence of heat than the inorganic bodies. When the qualitative examination of organic bodies was discussed, mention was made of the fact that many carbon compounds were decomposed under the influence of heat with the separation of carbon.

Other compounds, when heated at the ordinary temperature, rearrange themselves without alteration of their molecular magnitude, whilst some polymerize. Compounds, volatilizing undecomposed at ordinary pressure, may become decomposed when their vapours are conducted through tubes heated to redness, or by contact with metallic wires rendered incandescent by the electric current (C. 1901, **11**, 1042); as a rule, new bodies are then formed accompanied by partial carbonization. The splitting-off of hydrogen, the halogens, haloid acids, water, and ammonia leads to a more intimate union of the already combined carbon atoms, and carbon atoms which previously were not united with one another not infrequently combine to yield carbocyclic and heterocyclic bodies: *pyro-condensations* result (B. **11**, 1214).

In the special part of this volume, such results from heat action will be so frequently encountered that it becomes unnecessary to present examples at this time (comp. ethyl alcohol and chloroform).

It may suffice to mention coal tar, which contains the liquid bodies formed by the decomposition of coal under the influence of heat. This material is of the greatest importance both in the development of scientific, theoretical organic chemistry, as well as for technical chemistry (coal-tar industry). It is mainly composed of carbo- and heterocyclic compounds, stable under the influence of heat:

C_6H_6 Benzene.	$C_{10}H_8$ Naphthalene.	$C_{14}H_{10}$ Anthracene, Phenanthrene.	
C_4H_4S Thiophene.	C_5H_5N Pyridine.	C_9H_7N Quinoline and Isoquinoline.	$C_{13}H_9N$ Acridine.

2. ACTION OF LIGHT

Light exerts a great influence upon carbon compounds. The well-known reactions of this kind in the field of inorganic chemistry have corresponding cases in the province of organic chemistry.

Light is able to bring about the decomposition, the rearrangement, and the synthesis of carbon bodies. Just as the haloid salts of silver are decomposed with separation of silver, so, too, the *alkyl iodides* separate iodine under the influence of light. Hence their colourless solutions gradually become yellow and finally dark brown in colour. *Ethyl mercuric iodide* breaks down into mercurous iodide and butane. Experience shows that many other carbon derivatives decompose more or less rapidly when they are exposed to sunlight, hence they must be preserved in the dark or in vessels of brown coloured glass, which absorbs the chemically active rays of sunlight. It is technically important that an organic dye should resist the influence of light; most of them are not *fast* colours, but are bleached by light.

Of the decomposition-reactions produced by sunlight mention may be made of the change undergone by *succinic acid*, when mixed with uranium oxide; it loses carbon dioxide, and propionic acid results (A. **133**, 253):

$$CO_2H.CH_2.CH_2.CO_2H = CO_2 + CH_3.CH_2.CO_2H.$$

Solutions of tartaric acid and citric acid, when mixed with uranium oxide, are similarly decomposed by sunlight (A. **278**, 373).

An aqueous solution of *acetone* is partially hydrolized by sunlight into *acetic acid* and *methane* (B. **36**, 1582).

Mercury oxalate is decomposed by light into CO_2 and mercury; if ammonium chloride be present, calomel is formed. A similar reaction is the following:—

$$2HgCl_2 + C_2O_4(NH_4)_2 = Hg_2Cl_2 + 2CO_2 + 2NH_4Cl.$$

Sunlight often acts as a polymerizing agent. Solid *anthracene*, in the form of a vapour or solution is polymerized by sunlight or the light of a carbon or mercury arc lamp into *dianthracene*, a change which is completely reversed in the dark (Z. phys. Ch. **53**, 385). For similar cases of *phototropy* see B. **37**, 2236.

Finely divided *cinnamic acid* changes in sunlight to the dimeric modification *truxillic acid*, which returns to the simpler form under the influence of heat; *cinnamylidene malonic acid* behaves in the same way (Z. phys. Ch. **48**, 345).

For the polymerization of *benzaldehyde* see B. **36**, 1573.

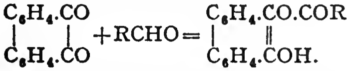
Geometric isomers (*alloisomers* or *stereoisomers*) are frequently changed into their stable forms by sunlight; for instance, maleïc acid into fumaric acid (B. **36**, 4267), allocinnamic acid into cinnamic acid; *anti*-oximes into *syn*-oximes (B. **36**, 4268; **37**, 180).

The combination of *carbon monoxide* and chlorine, forming *carbonyl chloride* or *phosgene* (*Davy*) is analogous to the complete union of hydrogen and chlorine, forming hydrogen chloride, and of benzene and chlorine or bromine to form hexa-chloro- or hexabromo-benzene, in sunlight:

$$H_2 + Cl_2 = 2HCl; \quad CO + Cl_2 = COCl_2; \quad C_6H_6 + 3Cl_2 = C_6H_6Cl_6.$$

The action of chlorine upon methane (p. 72), formaldehyde (B. **29**, R. 88), and other carbon derivatives which can be substituted, is much influenced by sunlight.

The experiments conducted by *Klinger* show that the chemical action of sunlight is susceptible of more extended application than it has yet found, and that compounds can be produced by it, which could only be prepared in the ordinary chemical way by most powerful or highly specialized means. He found that ethereal solutions of benzoquinone, benzil, and phenanthraquinone are reduced, with the formation of aldehyde. Further, that acetaldehyde, isovaleraldehyde, and benzaldehyde unite, under the influence of sunlight, with phenanthraquinone, in accordance with the equation (A. **249**, 137):



$$\begin{array}{l} C_6H_4.CO \\ \mid \qquad \mid \\ C_6H_4.CO \end{array} + RCHO = \begin{array}{l} C_6H_4.CO.COR \\ \mid \qquad \| \\ C_6H_4.COH. \end{array}$$

Isovaleraldehyde and benzaldehyde also unite directly with benzoquinone, but in a still more striking manner, in that a *nucleus-synthesis* (p. 75) results. With benzaldehyde the reaction proceeds as follows:—

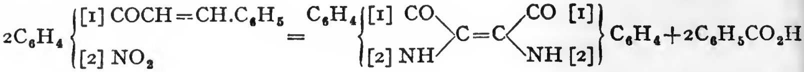
$$C_6H_4O_2 + C_6H_5.COH = C_6H_5.CO.C_6H_3(OH)_2$$

Benzoquinone. Benzaldehyde. Dihydroxybenzophenone—isomeric with the expected Monobenzoyl Hydroquinone.

Sunlight reduces a carbonyl group in alcoholic solution, and at the same time the alcohol becomes oxidized to aldehyde, as for instance, benzophenone and acetophenone yield the corresponding pinacones; quinone oxidizes glycerol to glycerose, erythritol to erythrose, mannitol to mannitose, dulcitol to dulcitose, dextrose to dextrosone, whilst in each case the quinone changes to quinhydrone.

Aromatic nitro-bodies readily give up their oxygen to alcoholic or aldehydic groups under the influence of sunlight: nitrobenzene and alcohol give aniline and quinaldine; nitrobenzene and benzaldehyde yield a mixture of benzoic acid, nitrosobenzene, β-phenylhydroxylamine and products of further interaction; *o*-nitrobenzaldehyde changes completely into *o*-nitrosobenzoic acid; *o*-nitrobenzal aniline gives *o*-nitrosobenzanilide, and so on (*Ciamician* and *Silber*, B. **37**, 3425; B. **38**, 1176, 3813).

o-Nitrobenzylidene acetophenone in ethereal solution is changed by sunlight to indigo and benzoic acid (*Engler* and *Dorant*, B. **28**, 2497):



The study of these reactions is specially important in the interpretation of the chemical changes occurring in plants.

3. ACTION OF ELECTRICITY

Some of the reactions induced by the aid of electricity possess great value for synthetic organic chemistry. The only method which will cause the union of free hydrogen with free carbon, consists in the action of the electric discharge upon the two elements. *Berthelot* showed that carbon and hydrogen combined to form acetylene on the passage of the electric spark between carbon points in an atmosphere of hydrogen: $2C+H_2=CH\equiv CH$. Small quantities of methane CH_4, and ethane C_2H_6 were also present, as was found later (C. 1901, II. 576). Fig. 10 represents the apparatus in which this important synthesis was carried out (A. chim. phys.; [4] **13**, 143; B. **23**, 1638; C. 1897, I. 24).

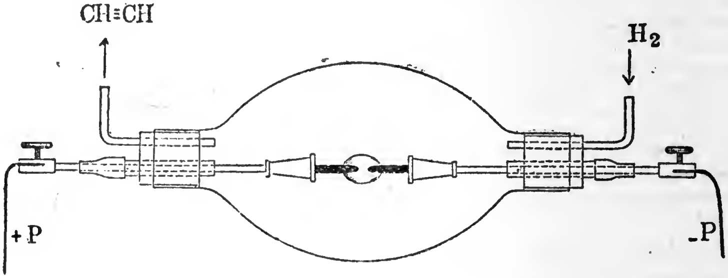
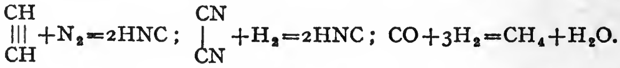


FIG. 10.

Acetylene and nitrogen (A. **150**, 60) as well as cyanogen and hydrogen, unite to yield hydrocyanic acid under the influence of electric discharges (C. r. **76**, 1132); and carbon monoxide and hydrogen form methane (Brodie, A. **169**, 270).



$$\begin{array}{c}CH\\|||\\CH\end{array}+N_2=2HNC;\quad \begin{array}{c}CN\\|\\CN\end{array}+H_2=2HNC;\quad CO+3H_2=CH_4+H_2O.$$

An important application of the heat derived from electricity is the preparation of the carbides in the electric furnace (*Moissan*),* where temperatures of about 3000° can easily be reached. Calcium and aluminium carbides are of the

---

* Der elektrische Ofen, *H. Moissan*, translated into German by Zettel, 1900.

greatest significance to organic chemistry, because water liberates from them acetylene and methane respectively (comp. p. 67).

Other thermal reactions can also be effected, such as passing the vapours of carbon compounds over a metallic spiral heated to incandescence by an electric current (C. 1901, II. 1042; see also B. **18**, 3350).

Kolbe decomposed the aqueous solutions of the potassium salts of monobasic carboxylic acids, especially potassium acetate, by the electric current, and thus prepared dimethyl or ethane. The following equation represents the electrolysis of potassium acetate:—

$$\begin{array}{l} \overbrace{\mathrm{CH_3}\vdots\mathrm{CO_2}}^{+}\,\big|\,\overbrace{\mathrm{K}\quad\mathrm{HO}\vdots\mathrm{H}}^{-} \\ \mathrm{CH_3}\vdots\mathrm{CO_2}\,\big|\,\mathrm{K}+\mathrm{HO}\vdots\mathrm{H} \end{array} = \begin{array}{l} \overbrace{\mathrm{CH_3}\quad\mathrm{CO_2}}^{+}\quad\overbrace{\mathrm{KOH}\quad\mathrm{H}}^{-} \\ \;|\qquad\qquad\qquad\qquad\qquad\;| \\ \mathrm{CH_3}+\mathrm{CO_2}+\mathrm{KOH}+\mathrm{H} \end{array}$$

Kekulé applied this reaction to the saturated dicarboxylic acids, *e.g.* succinic acid, and later he and *Aarland* extended it to the unsaturated dicarboxylic acids: fumaric acid, maleïc acid, mesaconic acid, citraconic acid, and itaconic acid (A. **131**, 79; J. pr. Ch. [2] **6**, 256; **7**, 142; comp. C. 1900, I. 1057; II. 171), with the production of the unsaturated hydrocarbons, ethylene, acetylene, and allylene. *Kolbe* and *Moore* obtained ethylene dicyanide from cyanacetic acid (B. **4**, 519). *Crum Brown* and *J. Walker* included the potassium salts of the acid esters of the dicarboxylic acids among these reactions, and obtained the neutral esters of dibasic acids, *e.g.* potassium ethyl malonate yielded succinic diethyl ester (A. **261**, 107; B. **24**, R. 36; A. **274**, 41; B. **26**, R. 369, 380). In the electrolysis of an alcoholic solution of sodium malonic diethyl ester *Mulliken* obtained ethane tetracarboxylic ester (B. **28**, R. 450).

V. Miller and *Hans Hofer* showed that by electrolysis of potassium acetate and potassium ethyl succinate, butyric ester is formed (B. **28**, 2429). *Mulliken* obtained ethane tetracarboxylic ester by electrolysis of an alcoholic solution of sodium malonic diethyl ester (B. **28**, R. 450).

Hamonet obtained the diamyl ether of butane-diol by the electrolysis of the amyl ether of potassium β-hydroxypropionate (C. 1901, I. 613). From the salts of ketocarboxylic acids, either alone or mixed with acetates, *Hofer* obtained by electrolysis ketones and diketones: pyroracemic acid yields diacetyl; lævulinic acid gives octane-2,7-dione, pyroracemic acid and acetic acid yield acetone (B. **33**, 650).

Hydrogen, generated by electrolysis, is a valuable means for reducing organic substances, as its action can be varied according to the liquid, current, voltage, cathode material, etc., employed for the particular requirements of the experiment. Aromatic nitro-bodies can be changed into their various reduction products—β-phenylhydroxylamines, aminophenol, azoxy- azo- or hydrazo-bodies, or into anilines (B. **28**, 2349; **29**, 1390; **38**, 3076). Many substances which are difficult to reduce by chemical methods, such as carboxyl groups in ketones, carboxylic acids and their esters, lactams, dicarboxylic acid imides, and others, can easily be reduced to CHOH or CH_2 groups in sulphuric acid solutions with cathodes possessing a high "supertension" (Cd, Hg, Pb) (*Tafel*, B. **33**, 2209; **37**, 3187, etc.; A. **348**, 199).

THE DIRECT COMBINATION OF CARBON WITH OTHER ELEMENTS

Before dealing with the systematic classification of the carbon compounds, some remarks may be made, by way of introduction, on the direct combination of carbon with other elements. Carbon and its various allotropic modifications are described in text-books on inorganic chemistry, but its affinity to other elements may well be discussed here also, since from the substances formed the innumerable compounds in organic chemistry are derived.

With one exception the combining power of carbon becomes operative only at high temperatures. In the finely-divided form of soot, carbon will combine with fluorine, to form tetrafluoromethane or carbon tetrafluoride

$$C+2F_2=CF_4.$$

Combination with hydrogen or chlorine can only be brought about under the influence of the electric arc, when carbon and hydrogen unite to form acetylene, the most reactive of all hydrocarbons, together with a little methane (p. 64):

$$2C+H_2=C_2H_2, \qquad C+2H_2=CH_4;$$

and chlorine and carbon combine to form hexachlorethane and perchlorobenzene:

$$2C+3Cl_2=C_2Cl_6; \qquad 6C+3Cl_2=C_6Cl_6.$$

Oxygen unites with carbon, producing carbon monoxide and carbon dioxide or carbonic acid gas:

$$C+O=CO; \qquad C+O_2=CO_2.$$

Which of these two substances is formed depends on the temperature of reaction. At very high temperatures only carbon monoxide is formed, the dioxide being produced below this. The affinity of carbon for oxygen is so great that at sufficiently high temperatures the most stable oxides give up their oxygen, so that carbon becomes the most important reducing agent for technical purposes.

Sulphur combines with carbon at high temperatures in only one proportion forming carbon disulphide—the sulphur analogue of the anhydride of carbonic acid:

$$C+S_2=CS_2.$$

Carbon, nitrogen, and hydrogen combine together when a mixture of nitrogen and hydrogen is passed between carbon poles of an electric arc, forming hydrocyanic acid, a reaction which possibly depends on the primary formation of acetylene:

$$C+N+H=HNC.$$
$$\text{or } 2C+2H=C_2H_2 \text{ and } C_2H_2+N_2=2HNC.$$

Similarly, carbon, nitrogen, and potassium or sodium, combine at high temperatures to form potassium or sodium cyanide. This reaction may also depend on the primary formation of potassium or sodium acetylide, followed by subsequent union with nitrogen. Or a metallic nitride may first be formed which then combines with carbon to produce the cyanide.

At very high temperatures carbon exhibits the capacity of combining directly with many elements of a metallic character to form carbides. Even in the early days the formation of iron carbide was proved to take place by the action of carbon on molten iron.

However, pure iron carbide is not known, but it appears that carbon combines with iron in various proportions. This is supported by the generation of a mixture of hydrocarbons when such a specimen of iron is dissolved in acids.

Carbon unites with the metals of the alkaline earths, calcium, strontium, and barium, in only one proportion. Such a carbide can be considered as being a metal-acetylene compound, which generates the gas on contact with water. It is prepared by the reduction of the oxide of the metal by carbon in the electric furnace:

$$2C + Ca(Sr, Ba) = C_2Ca(Sr, Ba).$$

Aluminium carbide, similarly prepared, gives off methane in contact with water:

$$3C + 4Al = C_3Al_4.$$

Beryllium carbide also yields methane; manganese carbide generates equal volumes of methane and hydrogen; the carbides of cerium, lanthanum, yttrium, samarium, C_2Me, give acetylene and methane; uranium carbide, C_3U_2 yields methane, hydrogen, and ethylene; whilst the last-named carbides also yield considerable quantities of fluid and solid hydrocarbons (C. R. **122**, 1462, etc.).

Whilst the carbides of the enumerated metals give off hydrocarbons when treated with acids or water, the carbides of boron, silicon, titanium, zirconium, vanadium, tungsten and chromium are extraordinarily stable and unusually hard; so much so that silicon carbide is employed, under the name of carborundum, in boring and polishing. The last three carbides are so far useless in the building up of carbon compounds.

The most important substances which have been formed by the direct union of carbon with other elements are:

Acetylene	C_2H_2
Calcium Carbide	C_2Ca
Methane	CH_4
Aluminium Carbide	C_3Al_4
Carbon Monoxide	CO
Carbon Dioxide	CO_2
Carbon Disulphide	CS_2
Hydrocyanic Acid	HNC
Potassium Cyanide	KNC.

These bodies are examples of widely different classes of organic compounds; methane and aluminium carbide are found at the head of the paraffin or acyclic saturated hydrocarbons, whilst acetylene and calcium carbide occupy a similar position among the unsaturated acyclic hydrocarbons possessing a triple bond between two carbon atoms. Carbon monoxide, hydrocyanic acid and potassium cyanide belong to the formic acid group of bodies which take the lead among the paraffin monocarboxylic acids of the acetic acid series; carbon dioxide and disulphide are among the carbonic acid groups which are the first of the paraffin dicarboxylic acids.

Of all these simple compounds of carbon, the most important is carbon dioxide, which forms the basis for the formation of the carbohydrates and fats during the process of assimilation in the vegetable organism; and also of the proteïns when nitrogen is taken up.

Since chemists have not yet succeeded in imitating in the laboratory the synthetic methods of plants, a large and increasing number of methods have been provided for linking together simple organic molecules for the construction of substances of complicated composition. These methods (see Synthetic Methods, Ring Formation, p. 75) depend partly on double decomposition, similar to the interaction of inorganic salts, but mainly on the property of one "unsaturated" molecule (p. 23) to unite with another; on reactions brought about by the agency of metals, especially Na, Mg, Al, Zn, Cu, or suitable compounds of them ; on the influence of acids ; and finally on rise of temperature, on sunlight or on electricity (pp. 61–65).

CLASSIFICATION OF THE CARBON COMPOUNDS.

The chemical union of the carbon atoms and the resulting character of the groups is the basis of the division of the carbon compounds into two principal classes: the **fatty** or **aliphatic** substances (from ἄλειφαρ, fat)—the *chain* or *acyclic carbon derivatives* or the *methane derivatives*, and the **cyclic** *compounds of carbon.*

The name of the first class is borrowed from the fats and fatty acids comprising it, which were the first derivatives to be studied accurately. They may be termed the marsh gas or *methane derivatives*, inasmuch as they all can be derived ultimately from methane, CH_4. They are further classified into *saturated* and *unsaturated* compounds. In the first of these, called also *limit compounds* or *paraffins*, the directly united quadrivalent carbon atoms are linked to each other by a single bond, so that the number of affinities still remaining to be satisfied in a chain of n carbon atoms is $2n+2$ (p. 23). Their general formula is, therefore, expressed in the form C_nX_{2n+2}, where X represents the affinities of the elements or groups directly combined with carbon. The unsaturated compounds result from the saturated by the loss of an even number of affinities in union with carbon. According to the number of affinities yet capable of saturation, the series are distinguished as C_nX_{2n}, C_nX_{2n-2}, etc.

The *methane derivatives* contain open carbon chains, the *cyclic derivatives* contain closed carbon chains, or rings. When carbon atoms alone constitute the ring, the resulting bodies are designated *carbocyclic compounds.*

Especially important among these cyclic compounds, are those in which the ring contains six carbon atoms with six free valencies. From these are derived substances which *Kekulé* named the *aromatic compounds* or *benzene derivatives.*

The importance of this group has gained for it a special position in the chemistry of carbon derivatives. Compared with the aliphatic compounds, they show such great differences in chemical behaviour that they were formerly regarded as a second and distinct class of organic bodies.

With the advances in organic chemistry, numerous compounds were being constantly discovered which contained carbon atoms united in a closed ring, but which approached the fatty bodies more closely than the aromatic derivatives in chemical behaviour. In the so-called hydroaromatic compounds the more pairs of hydrogen atoms which are attached to the benzene nucleus in them, the nearer they resemble, in chemical character, the aliphatic derivatives. Even more closely allied to the latter are those substances which contain a ring consisting of three, four, or five carbon atoms—

the *trimethylene* derivatives,
tetramethylene derivatives,
pentamethylene derivatives.

These constitute the passage from the aliphatic bodies to the *hydro-aromatic* compounds, with which the *aromatic* derivatives are so closely connected.

There are many carbon compounds containing "rings," in the formation of which not only carbon atoms, but also oxygen, sulphur, and nitrogen atoms take part.

Such bodies have been termed *heterocyclic compounds* (from ἕτερος, foreign). These derivatives will mainly be discussed at the conclusion of the remarks on the open chain bodies, from which they are derived by loss of water, hydrogen sulphide, or ammonia, and into which they can again be changed. A large class of heterocyclic bodies—more especially of the *thiophene*, *fufurane*, and *pyrrole* groups, the parent substances of the plant alkaloids: pyridine, quinoline, isoquinoline, etc.—like the aromatic bodies, possess a very stable ring. In the case of many heterocyclic bodies the open chain compounds, from which they may theoretically be deduced, do not actually exist. Therefore such heterocyclic compounds will be more conveniently discussed after the carbo- or isocyclic derivatives. Thus, the chemistry of the compounds of carbon may be divided into :—

I. Fatty Compounds: *Aliphatic compounds, methane derivatives, chain or acyclic carbon derivatives.*

II. Carbocyclic Compounds.

III. Heterocyclic Compouuds.

I. FATTY COMPOUNDS, ALIPHATIC SUBSTANCES OR METHANE DERIVATIVES, CHAIN OR ACYCLIC CARBON DERIVATIVES

I. HYDROCARBONS

The hydrocarbons may be regarded as the parent substances from which all other carbon compounds arise by the replacement of the hydrogen atoms by different elements or groups.

The fundamental conceptions of the linking of carbon atoms were put forward in the introduction. We distinguish, therefore, (1) *saturated* and (2) *unsaturated hydrocarbons.* The first contain only singly linked carbon atoms, whilst the unsaturated contain pairs of carbon atoms united doubly and trebly. As the first series has attained the limit of saturation by hydrogen, they are frequently called the *limit hydrocarbons*, or, after the first member of the series, marsh gas—the *methane hydrocarbons.* They are not very reactive, and are very stable; hence their designation as *paraffins* (from parum affinis).

A. Saturated or Limit Hydrocarbons, Paraffins, Alkanes,* Marsh Gas or Methane Hydrocarbons, C_nH_{2n+2}.

Nomenclature and Isomerism.—In consequence of the equivalence of the four affinities of carbon (see p. 21), no isomers are possible for the first three members of the series C_nH_{2n+2}:

CH_4	CH_3-CH_3	$CH_3-CH_2-CH_3$.
Methane.	Ethane.	Propane.

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* This word is seldom met with.—Tr.

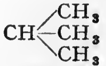
Formerly these hydrocarbons were designated the hydrides of univalent radicals—hydrocarbon residues or alkyls: methyl, ethyl, propyl, etc. Combined with the water residue or hydroxyl, they yielded the alcohols $C_nH_{2n+1}OH$. They were at first obtained from compounds of these radicals with other elements or groups: hence the names methyl hydride for methane, ethyl hydride for ethane, etc. The first known and most readily obtained derivatives of the alkyls C_nH_{2n+1} were their hydroxyl derivatives or the alcohols, *e.g.* C_2H_5OH, ethyl alcohol, and their halogen compounds.

At the suggestion of *A. W. Hofmann* their names were formed later by replacing the final syllable "yl" of the alkyls by the final syllable "ane," so that methane was used for methyl, ethane for ethyl, propane for propyl, etc., and for the homologous series the name *alkanes* was adopted.

Two structural isomers exist for the fourth member, C_4H_{10}:

$CH_3—CH_2—CH_2—CH_3$
Normal Butane.

and

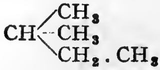


Trimethyl Methane
(Isobutane).

In the name trimethyl methane for isobutane, isomeric with normal butane, it is indicated that this substance is derived from methane by the replacement of three hydrogen atoms by three methyl groups.

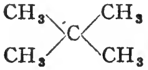
For the fifth member, pentane, C_5H_{12}, three isomers are possible:

$CH_3—CH_2—CH_2—CH_2—CH_3$
Normal Pentane.



Dimethyl Ethyl Methane.

and

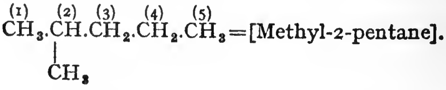


Tetramethyl Methane.

The number of theoretically possible isomers now increases rapidly. Hexane, C_6H_{14}, has 6 isomers; heptane, C_7H_{16}, 9 isomers; octane, C_8H_{18}, 18 isomers; tridecane, $C_{13}H_{28}$, 802 isomers. On the calculation of the number and nature of the isomeric paraffins, see Ch. Z. 1898, I. 395.

Commencing with the fifth member, the names are formed from the Greek words representing numbers.

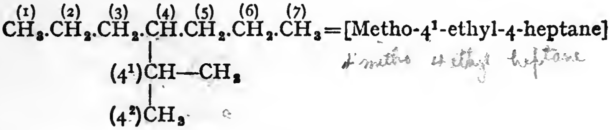
The "Geneva Convention" recommends the retention of the ending "ane," as first suggested by *A. W. Hofmann* (J. 1865, 413), for the hydrocarbons C_nH_{2n+2}. The hydrocarbons with branched carbon chains are considered as being alkyl substitution products of the normal hydrocarbons already contained in their formulæ, and the carbon atoms of this normal hydrocarbon are numbered. The numbering is begun with that carbon atom to which the side-chain is adjacent:



$$\overset{(1)}{CH_3}.\underset{\displaystyle CH_3}{\overset{(2)}{CH}}.\overset{(3)}{CH_2}.\overset{(4)}{CH_2}.\overset{(5)}{CH_3}=[\text{Methyl-2-pentane}].$$

The carbon atoms of a longer substituting radical are also numbered, and, indeed, with two numbers: the first, indicating the place where the side-chain is attached to the normal chain; and the second, beginning with the carbon atom which is joined to the main chain as number one.

Should a further alcohol radical attach itself to the middle carbon atom of the side-chain, then the expressions for the substituting radical are metho-, etho-, etc., instead of methyl-, ethyl-, etc.:



$$\begin{array}{l}\overset{(1)}{CH_3}.\overset{(2)}{CH_2}.\overset{(3)}{CH_2}.\overset{(4)}{CH}.\overset{(5)}{CH_2}.\overset{(6)}{CH_2}.\overset{(7)}{CH_3}=[\text{Metho-}4^1\text{-ethyl-}4\text{-heptane}].\\ \qquad\qquad\qquad\;\; | \\ \qquad\qquad (4^1)CH-CH_3 \\ \qquad\qquad\qquad\;\; | \\ \qquad\qquad (4^2)CH_3\end{array}$$

4 metho 4 ethyl heptane

The variation in structure of the carbon chain, or carbon nucleus, is the cause of isomerism in the paraffins. This type of isomerism is called chain- or nucleus-isomerism (p. 27).

Methods of Formation and Properties of the Paraffins.—The saturated hydrocarbons are formed in the dry distillation of wood, peat, bituminous shale, brown coal, coal, particularly the boghead and cannel coal rich in hydrogen; hence they are present in illuminating gas and in the light oils of coal-tar. They occur already formed in petroleum, particularly in that from America, which consists almost exclusively of them, and contains most members from methane to the highest. It is difficult to isolate the individual hydrocarbons from such mixtures. Before advancing to the general methods used in the preparation of the paraffins—methods by which each separate member can be easily obtained in pure condition—it will be best to discuss the two important bodies, *methane* and *ethane*.

(1) **Methane,** CH_4, *Methyl Hydride,* m.p. $-184°$; b.p.$_{760}$ $-164°$; D.$=8$ (H$=1$), or $0{\cdot}555$ (air$=1$) (C.r. **140,** 407), is produced in the decay of organic substances; it is, therefore, disengaged in swamps (marsh gas) and mines, in which, mixed with air, it forms fire-damp.

In certain regions, like Baku in the Caucasus and the petroleum districts of America, it escapes, in great quantities, from the earth. It is also present, in appreciable amount, in illuminating gas.

The synthesis of methane, the simplest hydrocarbon, from which all the fatty bodies may be derived, is particularly important. By the *synthesis of a carbon compound* is understood its formation from the elements, or from such carbon derivatives which can be obtained from the elements. Under proper conditions hydrogen and carbon may be directly combined, with the production of acetylene $CH\equiv CH$ (p. 64), together with only a small quantity of methane. The latter can be obtained (1) from carbon disulphide CS_2 (which may also be made directly from its constituents) if the vapours of this volatile substance, mixed with hydrogen sulphide gas, be passed over red-hot copper (*Berthelot*):

$$C+2S=CS_2; \qquad CS_2+2H_2S+8Cu=CH_4+4Cu_2S.$$

Or (2) the carbon disulphide may be converted by chlorine into carbon tetrachloride CCl_4, and this reduced, by nascent hydrogen (sodium amalgam and water):

$$CS_2+3Cl_2=CCl_4+S_2Cl_2; \qquad CCl_4+8H=CH_4+4HCl.$$

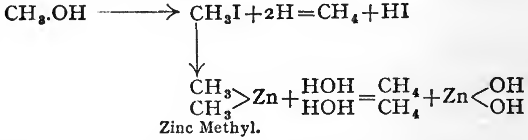
(3) Methane is also formed from carbon monoxide and hydrogen, if the mixture of gases be exposed in an induction tube to the action of electricity (p. 66), (A. **169,** 270), or is led over freshly reduced nickel (C.r. **134,** 514):

$$2C+O_2=2CO \qquad CO+3H_2=CH_4+H_2O.$$

(4) Aluminium carbide is decomposed, in the cold, by water, forming methane and aluminium hydroxide (B. **27**, R. 620; **29**, R. 613):

$$C_3Al_4 + 12H_2O = 3CH_4 + 2Al_2(OH)_6.$$

(5, 6) Methyl alcohol, or wood-spirit, $CH_3.OH$, can be converted into methane by first changing it to methyl iodide, and then reducing the latter with nascent hydrogen from moist zinc-copper, or with zinc dust in the presence of alcohol (B. **9**, 1810), or with potassium hydride (C. 1902, I. 708); or by preparing zinc methyl, $Zn(CH_3)_2$, from methyl iodide, and decomposing it with water:



$$\begin{tikzcd} CH_3.OH \arrow[r] & CH_3I + 2H = CH_4 + HI \arrow[d] \\ & \begin{matrix}CH_3\\CH_3\end{matrix}\!>Zn + \begin{matrix}HOH\\HOH\end{matrix} = \begin{matrix}CH_4\\CH_4\end{matrix} + Zn<\!\begin{matrix}OH\\OH\end{matrix} \end{tikzcd}$$

Zinc Methyl.

(7) Instead of using zinc methyl, it is more convenient to decompose an ether solution of methyl magnesium iodide with water:

$$CH_3MgI + H_2O = CH_4 + MgI.OH.$$

In the laboratory methane is made (8) by heating sodium acetate with soda-lime, of which the active ingredient is sodium hydroxide. The addition of the lime is for the purpose of protecting the glass vessel from the corroding action of the molten sodium hydroxide:

$$CH_3.CO_2Na + NaOH = CH_4 + Na_2CO_3.$$

Methane is a colourless gas possessing a slightly alliaceous odour. Its critical temperature is -82°, and its critical pressure 55 atm. At low temperatures it forms colourless needles. It is slightly soluble in water, but more readily in alcohol. It burns with a faintly luminous, yellowish flame, and forms explosive mixtures with air, oxygen, and chlorine:

$$\underset{1\text{ vol.}}{CH_4} + \underset{2\text{ vols.}}{2O_2} = \underset{1\text{ vol.}}{CO_2} + \underset{2\text{ vols.}}{2H_2O}\text{ (steam).}$$

It is decomposed into carbon and hydrogen by the continued passage of the electric spark. When mixed with two volumes of chlorine it explodes in direct sunlight, with separation of carbon,

$$CH_4 + 2Cl_2 = C + 4HCl.$$

In diffused sunlight chlorine substitution products are produced:

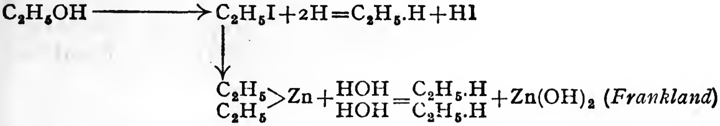
$CH_4 + Cl_2 = HCl + CH_3Cl$—Monochloromethane or *methyl chloride.*
$CH_3Cl + Cl_2 = HCl + CH_2Cl_2$—Dichloromethane or *methylene chloride.*
$CH_2Cl_2 + Cl_2 = HCl + CHCl_3$—Trichloromethane or *chloroform.*
$CHCl_3 + Cl_2 = HCl + CCl_4$—Tetrachloromethane or *carbon tetrachloride.*

Through methyl chloride methane may be converted into methyl alcohol, ethane, ethyl alcohol, and acetic acid.

Fluorine reacts explosively at -187°.

Ethane, *Ethyl Hydride, Dimethyl, Methyl Methane,* $CH_3.CH_3$, m.p. -172° (B. **33**, 637); b.p.$_{760}$ -84°; D.$_0$ (liquid) $= 0{\cdot}466$ (B. **27**, 2767, 3305). This hydrocarbon was discovered in 1848 by *Frankland* and *Kolbe.* It is formed (1) by the addition of hydrogen to the two unsaturated hydrocarbons, acetylene (p. 87) and ethylene (p. 81), when the multiple linkage of the carbon atoms is broken down.

Ethane may be obtained from ethyl alcohol by way of (2) ethyl iodide or (3) of zinc ethyl, just as methane was prepared from methyl alcohol:



$$\begin{tikzcd} C_2H_5OH \arrow[r] & C_2H_5I+2H=C_2H_5.H+HI \arrow[d] \\ & \begin{matrix}C_2H_5\\C_2H_5\end{matrix}\!\!>Zn+\begin{matrix}HOH\\HOH\end{matrix}=\begin{matrix}C_2H_5.H\\C_2H_5.H\end{matrix}+Zn(OH)_2 \text{ (\textit{Frankland})} \end{tikzcd}$$

Or (4) magnesium ethyl bromide (p. 72, Methane) may be decomposed by water; or (5) mercury ethyl by concentrated sulphuric acid:

$$C_2H_5MgBr+H_2O=C_2H_6+MgBr.OH$$
$$(C_2H_5)_2Hg+H_2SO_4=2C_2H_5.H+HgSO_4 \text{ (\textit{Schorlemmer})}.$$

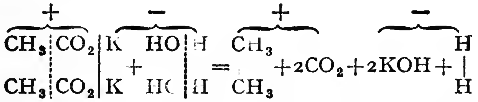
These last three methods led to the assumption that ethane was *ethyl hydride.* The following reactions show how ethane can be formed from the union of two methyl residues, and hence led to the view that the hydrocarbon was *dimethyl.* (6) Sodium is allowed to act on methyl iodide—the reaction is accelerated by the addition of one drop of acetonitrile (C. 1901, II. 24)—or (7) zinc methyl may be substituted for the metal:

$$2CH_3I+2Na=CH_3-CH_3+2NaI \text{ (\textit{Würtz})}.$$
$$2CH_3I+(CH_3)_2Zn=2CH_3-CH_3+ZnI_2.$$

A more convenient method (8) consists in heating acetic anhydride with barium peroxide:

$$2(C_2H_3O)_2O+BaO_2=C_2H_6+(C_2H_3O_2)_2Ba+2CO_2.$$

From a theoretical point of view (9) the electrolysis of a concentrated solution of potassium acetate (p. 65) (the method used by *Kolbe* (1848) by which he discovered ethane), is of great importance. The salt breaks down into its two electrochemical constituents—potassium, its electro-positive ion, appearing at the negative pole and separating hydrogen from water at that point, and the unstable electronegative ion radical $CH_3.CO_2$—, which immediately decomposes at the positive pole into $-CH_3$ and CO_2. Two methyl groups then unite to dimethyl, just as two hydrogen atoms combine to form a molecule of that element;



$$\overbrace{\begin{array}{c:c} CH_3 & CO_2 \\ & \\ CH_3 & CO_2 \end{array}}^{+}\left|\overbrace{\begin{array}{ccc} K & & HO \\ & + & \\ K & & HO \end{array}}^{-}\right|\begin{array}{c} H \\ \\ H \end{array} = \overbrace{\begin{array}{c} CH_3 \\ \\ CH_3 \end{array}}^{+}+2CO_2+\overbrace{2KOH+\begin{array}{c} H \\ | \\ H \end{array}}^{-}$$

Both *Kolbe* and *Frankland* believed that ethyl hydride $C_2H_5.H$ differed from dimethyl $CH_3.CH_3$. Such a difference was not possible in the light of the valence theory. By converting the hydrocarbon from $(C_2H_5)_2Hg$ and that obtained in the electrolysis of potassium acetate into the same ethyl chloride *Schorlemmer* (1863) proved the identity of ethyl hydride $C_2H_5.H$ and dimethyl $CH_3.CH_3$, thus confirming a fundamental requirement of the valence theory:

$$(C_2H_5)_2Hg\xrightarrow{H_2SO_4}C_2H_5.H\xrightarrow{Cl_2}C_2H_5Cl.$$
$$2CH_3.CO_2K\xrightarrow{\text{electric current}}CH_3.CH_3\xrightarrow{Cl_2}CH_3CH_2Cl.$$

Ethane is a colourless and odourless gas. Its critical temperature equals +34° and its critical pressure is 50·2 atmospheres. It acts like methane towards solvents.

Ethane can be converted into ethyl alcohol through its monochloro-substitution product.

Homologues of Methane and Ethane.—In preparing the homologous paraffins, the homologues of ethyl alcohol $C^nH_{2n+1}.OH$ and the saturated fatty acids are employed.

I. *Formation from compounds containing a like number of carbon atoms.*

(1) From the unsaturated hydrocarbons by the addition of hydrogen (see Ethane).

(2) By the reduction of alcohols, ketones, and carboxylic acids.

(*a*) The alcohol, for example ethyl alcohol, is changed to the chloride, bromide, or iodide, which is then reduced with nascent hydrogen, by means of zinc and hydrochloric acid, or sodium amalgam and alcohol. The iodide may alternatively be treated with aluminium chloride (B. **27**, 2766).

Thus, propane has been prepared from the two propyl iodides C_3H_7I by zinc and hydrochloric acid, as well as from isopropyl chloride by sodium-ammonium (C. 1905, II. 112). Trimethyl methane has been obtained by the action of zinc and hydrochloric acid on the iodide of tertiary butyl alcohol. Also, by heating the alkyl iodides with zinc and water in sealed tubes at 120–180°, paraffins are obtained.

(*b*) The saturated fatty acids, $C_nH_{2n+1}.CO_2H$, particularly the higher members of the series, may be converted into the corresponding paraffins by heating them with concentrated hydriodic acid and red phosphorus to 200–250°:

$$\underset{\text{Stearic Acid.}}{C_{17}H_{35}.CO_2H}+6HI=\underset{\text{Octadecane.}}{C_{18}H_{38}}+3I_2+2H_2O.$$

(*c*) The ketones (*q.v.*), resulting from the distillation of the calcium salts of fatty acids, change to paraffins when they are heated with hydriodic acid. It is more practical first to prepare the keto-chlorides (p. 93) by the action of phosphorus pentachloride upon the ketones, and then to reduce them.

The last two reactions especially were applied (B. **15**, 1687, 1711; **19**, 2218) in the preparation of the normal hydrocarbons from nonane, $CH_3(CH_2)_7CH_3$, to tetracosane $CH_3(CH_2)_{22}CH_3$.

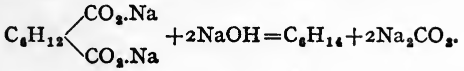
(3) Or, the alcohol is changed by way of the alkyl iodide into a zinc or mercury alkyl, and the zinc alkyls are then decomposed by water (see Methane and Ethane), and the mercury alkyls by acids (see Ethane). Also, the easily prepared magnesium halogen alkyls may be decomposed by water, thereby liberating the paraffin (C. 1901, I. 1000).

II. *Formation from compounds rich in carbon, with loss of carbon.*

(4) A mixture of the salts of fatty acids (the carboxyl derivatives of the alkyls) and sodium or potassium hydroxide, or better, soda-lime, is subjected to dry distillation (see Methane).

When the higher fatty acids are subjected to this treatment the usual products are the ketones; hydrocarbons, however, are produced when sodium methoxide is used in place of soda-lime (B. **22**, 2133).

The dibasic acids are similarly decomposed:



$$C_6H_{12}<\begin{matrix}CO_2.Na\\ CO_2.Na\end{matrix}+2NaOH=C_6H_{14}+2Na_2CO_3.$$

III. *Methods of Formation, consisting in the union of alkyls, previously not directly combined, with one another.*

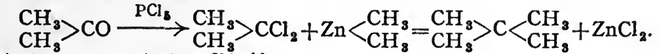
(5) *Method of Würtz:* this consists in the action of sodium (or reduced silver or copper) on the bromides or iodides of the alcohol radicals in ethereal solution (see Ethane). Thus with sodium:

C_2H_5I	yields	$C_2H_5.C_2H_5$ Diethyl or normal Butane.
$CH_3CH_2CH_2I$	,,	$C_3H_7.C_3H_7$ Di-normal-propyl or normal Hexane.
$CH_3CH_2CH_2CH_2I$	,,	$C_4H_9.C_4H_9$ Di-normal-butyl or normal Octane.

The addition of one or two drops of acetonitrile accelerates the reaction (C. 1901, II. 24). This reaction proceeds especially easily with normal alkyl iodides of high molecular weights. Thus, *Hell* and *Hägele,* by fusing myricyl iodide with sodium, obtained *hexacontane,* $C_{60}H_{122}$, a compound having by far the longest normal carbon chain known up to the present time (B. **22,** 502). By employing a mixture of the iodides of two primary alcohols, hydrocarbons result from the union of the differing radicals. The iodides of optically active (p. 30) alcohols, *e.g.*, optically active amyl iodide, yield optically active paraffins (B. **27,** R. 852). Magnesium acts similarly to sodium on the iodides of the higher alcoholic radicals (C. 1901, I. 999; B. **36,** 3083), for example: tertiary butyl bromide and magnesium give *hexamethyl ethane* $(CH_3)_3C.C(CH_3)_3$, which is also formed by the interaction of pentamethyl ethyl bromide and methyl magnesium bromide (C. 1906, II. 748):

$$C(CH_3)_3.C(CH_3)_2Br+CH_3MgBr=(CH_3)_3C.C(CH_3)_3+MgBr_2.$$

(6) Action of zinc alkyls on alkylogens (see Ethane) and ketone chlorides: thus, tertiary butyl iodide and zinc ethyl give trimethyl ethyl methane (B. **32,** 1445; **33,** 1905); also acetone chloride or β-dichloropropane is changed by zinc methyl into tetramethyl methane:



$$\begin{matrix}CH_3\\ CH_3\end{matrix}>CO\xrightarrow{PCl_5}\begin{matrix}CH_3\\ CH_3\end{matrix}>CCl_2+Zn<\begin{matrix}CH_3\\ CH_3\end{matrix}=\begin{matrix}CH_3\\ CH_3\end{matrix}>C<\begin{matrix}CH_3\\ CH_3\end{matrix}+ZnCl_2.$$

Acetone. Acetone Chloride.

(7) By the electrolysis of the alkali salts of fatty acids (see Ethane). *Alcohols* may occur as subsidiary products: methyl alcohol from potassium acetate; ethyl alcohol from sodium propionate. Also unsaturated hydrocarbons, as isobutylene, may be produced from trimethyl acetic acid.

Synthetic Methods.—The last group of reactions comprises synthetic methods for the building up of hydrocarbons. In the formation of methane from carbon disulphide and hydrogen sulphide it was explained what in general was understood by the synthesis of a carbon compound. Those reactions in which carbon atoms, not before combined with one another, become united, claim particular importance in the synthesis of the compounds of carbon (*Lieben,* A. **146,** 200). Most of the carbon derivatives are due in the first place to the combining power of the carbon atoms among themselves. Such reactions are the *synthetic methods of organic chemistry* in the more restricted sense. In the future we shall designate them *nucleus-syntheses.* They genetically bind together the members of an homologous series, and the homologous series among themselves, and the open carbon chains with closed chains, or rings.

The *synthesis* of a carbon compound from derivatives of carbon of known structure is one of the most important means employed for the recognition of its structure or constitution.

Properties of the Paraffins.—The lowest members of the series up to butane and tetramethyl methane are gases at the ordinary temperature. The middle members are colourless liquids, with a faint but characteristic odour. The higher representatives, beginning with *hexadecane*, $C_{16}H_{34}$, m.p. 18°, are crystalline solids. The highest members are only volatile without decomposition under reduced pressure. The boiling points rise with the molecular weights; the difference for CH_2 is at first 30°, and with the higher members it varies from 25° to 13°.

The boiling points of *propane*, of the two *butanes*, the three *pentanes*, and the five known *hexanes* are given in the following table. All the theoretically possible isomers are known:

		Structural Formula.	B.p. at 760 m.m.
C_3H_8	Propane	$CH_3.CH_2.CH_3$	−45° (B. **27**, 3306; C. 1905, II. 112).
C_4H_{10}	Normal Butane	$CH_3.CH_2.CH_2.CH_3$	+ 1° (B. **27**, 2768).
	Trimethyl Methane	$CH_3.CH(CH_3)_2$	−17°
C_5H_{12}	Normal Pentane	$CH_3.[CH_2]_3.CH_3$	+38°
	Dimethyl Ethyl Methane	$CH_3CH_2.CH(CH_3)_2$	+30°
	Tetramethyl Methane	$C(CH_3)_4$	+ 9° (B. **32**, 1449).
C_6H_{14}	Normal Hexane	$CH_3[CH_2]_4CH_3$	+71°
	Methyl Diethyl Methane	$CH_3CH(C_2H_5)_2$	+64°
	Dimethyl Propyl Methane	$CH_3CH_2.CH_2CH(CH_3)_2$	+62°
	Di-isopropyl	$(CH_3)_2CH.CH(CH_3)_2$	+58°
	Trimethyl Ethyl Methane	$CH_3CH_2.C(CH_3)_3$	+49° (B. **32**, 1449).

It is evident from this table that among isomers those with normal structure (p. 27) have the highest boiling points: generally the accumulation of methyl groups in the molecule lowers the boiling points. The same regularity will be again encountered in other homologous series. The subjoined table contains the melting points, boiling points, and the specific gravities of the known normal paraffins:

		M.P.		B.P.	Sp. Gr.	
Heptane	C_7H_{16}	. . .	Under 760 mm. pressure.	98·4°	0·7006 (0°)	
Octane	C_8H_{18}	. . .		125·5°	0·7188 (0°)	
Nonane	C_9H_{20}	−51°		149·5°	0·7330 (0°)	
Decane	$C_{10}H_{22}$	−32°		173°	0·7456 (0°)	
Undecane	$C_{11}H_{24}$	−26·5°		194·5°	0·7745	at their m.p.
Dodecane	$C_{12}H_{26}$	−12°		214°	0·773	
Tridecane	$C_{13}H_{28}$	−6·2°		234°	0·775	
Tetradecane	$C_{14}H_{30}$	+5·5°		252·5°	0·775	
Pentadecane	$C_{15}H_{32}$	+10°		270·5°	0·775	
Hexadecane	$C_{16}H_{34}$	+18°		287·5°	0·775	
Heptadecane	$C_{17}H_{36}$	+22·5°		303°	0·776	
Octadecane	$C_{18}H_{38}$	+28°		317°	0·776	
Nonadecane	$C_{19}H_{40}$	+32°	Under 15 mm. pressure.	330°	0·777	
Eicosane	$C_{20}H_{42}$	+36·7°		205°	0·777	
Heneicosane	$C_{21}H_{44}$	+40·4°		215°	0·778	
Docosane	$C_{22}H_{46}$	+44·4°		224·5°	0·778	
Tricosane	$C_{23}H_{48}$	+47·7°		234°	0·778	
Tetracosane	$C_{24}H_{50}$	+51·1°		243°	0·778	
Heptacosane	$C_{27}H_{56}$	+59·5°		270°	0·779	
Hentriacontane	$C_{31}H_{64}$	+68·1°		302°	0·780	
Dotriacontane	$C_{32}H_{66}$	+70.0°		310°	0·781	
Pentatriacontane	$C_{35}H_{72}$	+74·7°		331°	0·781	
Dimyricyl	$C_{60}H_{122}$	+102°		. .	. . .	

n-Heptane is formed during the distillation of the resin of *Pinus Sabiniana* and *Pinus Jeffreyi* (C. 1901, I. 1143). *Methyl ethyl propyl methane*, one of the isomers of n-heptane, is the simplest hydrocarbon containing an asymmetric C-atom (see p. 29). Its dextro-rotatory form, b.p. 91°, and $[\alpha]^D = +9{\cdot}5^\circ$, is prepared by the action of sodium on ethyl iodide (B. **37**, 1046).

Of the isomers of n-octane, *hexamethyl ethane* $(CH_3)_3C.C(CH_3)_3$, m.p. 104°, b.p. 107°, should be mentioned on account of its high vapour pressure, and similarity to perchlorethane (p. 95); it results from the reaction of pentamethyl ethyl bromide and methyl magnesium bromide (C. 1906, II. 748).

Heptacosane and hentriacontane have been found in American tobacco (C. 1901, II. 395).

The saturated hydrocarbons are insoluble in water, whilst the lower and intermediate members are readily soluble in alcohol and ether. The solubulity in these last two solvents falls with increasing molecular weight: dimyricyl, $C_{60}H_{122}$, m.p. 102°, is scarcely soluble in either of them.

The specific gravities of the liquid and solid hydrocarbons increase with their molecular weights, but are always less than that of water. It is remarkable that in the case of the higher members the specific gravities at the point of fusion are almost the same. They rise from 0·773 for dodecane $C_{12}H_{26}$, to but 0·781 for pentatriacontane, $C_{35}H_{72}$; consequently the molecular volumes are nearly proportional to the molecular weights (B. **15**, 1719; A. **223**, 268).

The paraffins are not absorbed by bromine in the cold or sulphuric acid, being in this way readily distinguished and separated from the unsaturated hydrocarbons. They are very stable, and, in consequence, react with difficulty. Fuming nitric acid and even chromic acid are without much effect upon them in the cold; when heated, however, they generally are oxidized directly to carbon dioxide and water. Recently, n-hexane and n-octane have been nitrated by heating them with dilute nitric acid. The isomers are more easily attacked than are the n-paraffins (see nitro-derivatives of the paraffins). When acted on by chlorine or bromine they yield substitution products.

By means of the latter the paraffins can easily be converted, as observed under methane and ethane, into other derivatives.

When nitrating and chlorinating the paraffins and the paraffin groups in carbon compounds, the general rule holds good that in most cases the tertiary hydrogen atom is easier to replace than the secondary, and the secondary than the primary (B. **32**, 1443).

Technical Preparation of the Saturated Hydrocarbons.—The hydrocarbons, readily obtainable on a commercial scale, are employed in enormous quantities for illuminating and heating purposes, are also used as solvents for fats, oils, and resins, as lubricants for machinery, and as salves.

The great abundance of *mineral oil, petroleum, rock-oil, naphtha*, is of the utmost importance to chemical industry. The oil is very widely distributed, but only occurs in certain districts in sufficiently large quantities to be usefully worked. It is especially abundant in Pennsylvania and Canada, although it is also found in the Crimea along the Black Sea, and at Baku on the shore of the Caspian, as well as in Hungary, Galicia, Roumania, and the Argentine Republic. Its occurrence in Germany, in Hanover, and in Alsace is limited. Since the year 1859 efforts have been put forth to work oil wells which have been known for many years, and also to make new borings. (See *Höfer*. Das Erdöl und seine Verwandten, 1906.)

The following data give some idea of the vast quantities in which this product is handled; in 1904 the world's production of crude naphtha was about 28·6 million tons, of which America contributed 15·0 million tons, Russia 10·6, Dutch Indies 1·0, etc. Since 1901 the production in Russia has fallen, whilst in America and most other countries it has risen.

In a crude state it is a thick, oily liquid, of brownish colour, which appears green by reflected light. Its more volatile constituents are lost upon exposure to the air; it then thickens and eventually passes into *asphaltum*. The greatest differences prevail in the various kinds of petroleum. It is very probable that petroleum has been produced by the decomposition of the fatty constituents of fossil animals. This took place under the influence of great pressure and the heat of the earth. The distillation of fish blubber under pressure has yielded products very similar to the American petroleum (*Engler*, B. **26**, 1449; **30**, 2908; **33**, 7; *Ochsenius*, B. **24**, R. 594).

Mendelejeff first suggested that it was possible for petroleum to be formed by the action of water on the metallic carbides in the interior of the earth, and *Moissan* subsequently came to the same conclusion during his investigations on the carbides (B. **29**, R. 614).

Apart from geological evidence the following facts contradict this view and favour an organic origin for petroleum: (1) a small nitrogen content (pyridine bases) in most specimens of petroleum; (2) the optical activity of the higher fractions, which according to present knowledge could not be formed by such a synthesis, as this would lead to the formation of racemic (inactive) bodies only (p. 56, Ch. Z. 1096, 711).

The constituents of American petroleum possessing a low boiling point, consist almost entirely of saturated hydrocarbons, both normal paraffins and those of the general formulæ $R_2.CH.CH.R_2$, CHR_3, and CR_4 (B. **32**, 1445; **33**, 1905). Yet small quantities of some of the benzene hydrocarbons (cumene and mesitylene) are present. The crude oil has a specific gravity of 0·8–0·92, and distils from 30° to 360° and higher. Various products, of technical value, have been obtained from it by fractional distillation: *Petroleum spirit*, sp. gr. 0·665–0·67, distilling about 50–60°, consists of pentane and hexane; *petroleum benzine*, sp. gr. 0·68–0·72 (not to be confounded with the benzene of coal tar), distils at 70–90°, and is composed of hexane and heptane; *ligroine*, boiling from 90° to 120°, consists principally of heptane and octane; *refined petroleum*, called also *kerosene*, boils from 150° to 300°, sp. gr. 0·78–0·82. (For the apparatus of *Engler* and *Abel* intended to determine the flash point of petroleum, see *Elsner:* Die Praxis des Chemikers, [1893] 399, 401; B. **29**, R. 553.) The portions boiling at high temperatures are applied as lubricants; small amounts of *vaseline* and *paraffins* (see below) are obtained from them.

Caucasian petroleum (from Baku) has a higher specific gravity than the American; it contains far less of the light volatile constituents, and distils at about 150°. Upwards of 10 per cent. of benzene hydrocarbons (C_6H_6 to cymene $C_{10}H_{14}$) as well as less saturated hydrocarbons, C_nH_{2n-8}, etc., may be extracted by shaking it with concentrated sulphuric acid (B. **19**, R. 672). These latter are also present in the German oils (Naphthenes, B. **20**, 595). That portion of the Caucasian petroleum insoluble in sulphuric acid consists almost exclusively of C_nH_{2n} hydrocarbons, the naphthenes, which belong to the *cycloparaffins* (p. 80).

and are probably chiefly cyclopentanes, mixed, perhaps, with *aromatic hydrides*; hexahydroxylene = octonaphthene, hexahydromesitylene = non-naphthene (B. **16**, 1873; **18**, R. 186; **20**, 1850, R. 570). From its composition, *Galician* petroleum occupies a position intermediate between the American and that from Baku (A. **220**, 188).

German petroleum also contains benzene hydrocarbons (extractable by sulphuric acid), but consists chiefly of the saturated hydrocarbons and naphthenes (*Krämer*, B. **20**, 595). The so-called petrolic acids are present in all varieties of petroleum, particularly that from Russia (*Beilstein*, Hdb. d. org. Ch., III. Ed. 522, C. 1897, I. 1153).

Products similar to those occurring in mineral oil are yielded by the tars resulting from the dry distillation of brown-coal (from the province of Saxony), and of the bituminous shale (in Scotland and the Gewerkschaft Messel, Darmstadt, in Hesse). These tars contain appreciably greater quantities of unsaturated hydrocarbons associated with the naphthenes and paraffins, as well as the aromatic hydrocarbons present in the tar from bituminous shales (*Heusler*, B. **28**, 488; **30**, 2743; Z. anorg. Ch. 1896, 319). Large quantities of solid paraffins are also present in these tar oils.

By *solid paraffin* is ordinarily understood the high-boiling solid hydrocarbons (above 300°) obtained by the distillation of the tar of wood, peat, lignite, and bituminous shales. They were discovered by *Reichenbach* (1830) in the tar from the beech-wood, and, in nature occur more abundantly in the petroleum from Baku than in that from America. In the free state they constitute the class of mineral waxes, which includes *ozokerite* (in Galicia and Roumania, and Tscheleken, an island in the Caspian Sea, B. **16**, 1547); and *neftigil* (in Baku). For their purification the crude paraffins are treated with concentrated sulphuric acid, to destroy the resinous constituents, and are then re-distilled. Ozokerite that has been bleached without distillation, bears the name *ceresine*, and is used as a substitute for beeswax. Paraffins that liquefy readily and fuse between 30° and 40° are known as *vaselines*, and find application as salves.

When pure, the solid paraffins form a white, translucent, leafy, crystalline mass, soluble in ether and hot alcohol. They melt between 45° and 70°, and are essentially a mixture of saturated hydrocarbons boiling above 300°, but appear to contain also those of the formula C_nH_{2n}. Chemically, paraffin is extremely stable, and is not attacked by fuming nitric acid. Substitution products are formed when chlorine acts upon paraffin in a molten state.

B. Unsaturated Hydrocarbons

1. C_nH_{2n} : Olefines, Alkylenes, Alkenes.
2. C_nH_{2n-2} : Acetylene Series, Alkines.
3. C_nH_{2n-2} : Diolefine Series, Alkadiënes.
4. C_nH_{2n-4} : Olefinacetylene Series.
5. C_nH_{2n-6} : Diacetylene Series.

1. OLEFINES or ALKYLENES, C_nH_{2n}

The hydrocarbons of this series contain two hydrogen atoms less than the saturated hydrocarbons. All contain two adjacent carbon atoms united doubly to each other, or, as commonly expressed, they contain a double carbon linkage. The olefines readily take up two univalent atoms or radicals, whereby the double carbon union becomes converted into a single one: paraffins or their derivatives result.

The names of the olefines are derived from the names of the alcohols containing a like carbon content, with the addition of the suffix "ene": ethylene from ethyl, propylene from propyl, and finally for the series we have the name: *alkylenes.* In the "Geneva names" the *yl* of the alcohol radicals is replaced by "ene": [ethene] from ethyl, [propene] from propyl, and for the series: *alkenes.* In long series the position of the double union is indicated by an added number (p. 70). Methylene, $=CH_2$, the hydrogen compound corresponding to CO, has thus far resisted isolation as completely as $-CH_2$. Two $=CH_2$ groups invariably unite to form ethylene —the first member of the series. Beginning with the second member of the series, propylene, we find, as we advance, that the olefines have isomers in the ring-shaped hydrocarbons—the **cycloparaffins** or **cyclic limit hydrocarbons**:

Propylene is isomeric with *trimethylene*—[Cyclopropane] . $\left.\begin{matrix}CH_2\\CH_2\end{matrix}\right>CH_2$

The three butylenes are isomeric with *tetramethylene*—[Cyclobutane] $\begin{matrix}CH_2.CH_2\\CH_2.CH_2\end{matrix}$

The five amylenes are isomeric with *pentamethylene*—[Cyclopentane] $\left.\begin{matrix}CH_2.CH_2\\CH_2.CH_2\end{matrix}\right>CH_2$

The hexylenes are isomeric with *hexamethylene*— . . . *hexahydrobenzene* [Cyclohexane] $\begin{matrix}CH_2-CH_2-CH_2\\CH_2-CH_2-CH_2\end{matrix}$

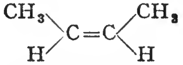
The heptylenes are isomeric with—*heptamethylene* . . . *suberane* [Cycloheptane] $\left.\begin{matrix}CH_2.CH_2.CH_2\\CH_2.CH_2.CH_2\end{matrix}\right>CH_2$

The cycloparaffins are more closely allied, in chemical character, to the paraffins than to their isomeric olefines, as they only contain singly linked carbon atoms. They lack in additive power, as the addition of hydrogen could only result in a rupture of the ring. Together with their derivatives, the cycloparaffins form the transition from fatty bodies to the aromatic compounds. They will not be considered in the discussion of the olefines.

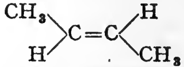
Olefine isomers appear first with butylene. Three modifications are possible and are known:

(1) $CH_3-CH_2-CH=CH_2$ Butylene [Butene-1]. (2) $CH_3-CH=CH-CH_3$ Pseudobutylene [Butene-2]. (3) $CH_2=C(CH_3)_2$ Isobutylene [Methyl Propene].

Pseudobutylene has been obtained in two geometrical isomeric modifications (p. 33) (A. 313, 207):



Plane-symmetrical Pseudobutylene, b.p. 1–1·5°.



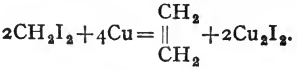
Axially-symmetrical Pseudobutylene, b.p. 2·5°.

Five olefines of the formula C_5H_{10} are possible.

Ethylene may be taken as being typical of the olefines.

Ethylene, $CH_2=CH_2$ [*Ethene*], *Elayl;* m.p. −169°, b.p.$_{760}$ −105°, is also known as *oil-forming gas,* because, by the action of chlorine, it yields an oily compound, ethylene chloride (*q.v.*). This property has given the name to the whole series. Ethylene is formed during the dry distillation of many organic bodies, and is, therefore, present in illuminating gas to the extent of 4 to 5 per cent.

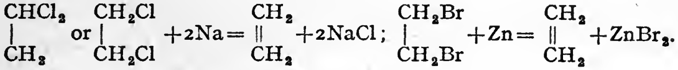
Methods of Formation.—(1) By heating methylene iodide, CH_2I_2, with metallic copper to 100° in a sealed tube (*Butlerow*):



$$2CH_2I_2+4Cu=\begin{matrix}CH_2\\ \parallel\\ CH_2\end{matrix}+2Cu_2I_2.$$

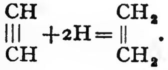
(2) By the action of metallic sodium on ethylidene chloride

(*Tollens*) and ethylene chloride, as well as from zinc and ethylene bromide:



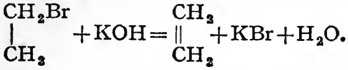
$$\begin{array}{l}CHCl_2\\ |\\ CH_3\end{array} \text{ or } \begin{array}{l}CH_2Cl\\ |\\ CH_2Cl\end{array} + 2Na = \begin{array}{l}CH_2\\ \|\\ CH_2\end{array} + 2NaCl; \quad \begin{array}{l}CH_2Br\\ |\\ CH_2Br\end{array} + Zn = \begin{array}{l}CH_2\\ \|\\ CH_2\end{array} + ZnBr_2.$$

(3) By the action of zinc and ammonia on copper acetylide; and of a mixture of acetylene and hydrogen in the presence of finely divided metals, such as nickel:



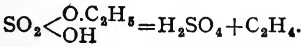
$$\begin{array}{l}CH\\ |||\\ CH\end{array} + 2H = \begin{array}{l}CH_2\\ \|\\ CH_2\end{array}.$$

(4) When alcoholic potassium hydroxide acts on ethyl bromide:



$$\begin{array}{l}CH_2Br\\ |\\ CH_3\end{array} + KOH = \begin{array}{l}CH_2\\ \|\\ CH_2\end{array} + KBr + H_2O.$$

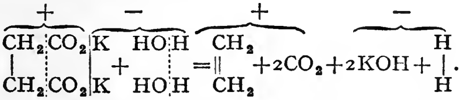
(5) Upon heating ethyl sulphuric acid (p. 82). This is the method usually pursued in the laboratory for the preparation of ethylene (A. **192**, 244):



$$SO_2{<}\begin{array}{l}O.C_2H_5\\ OH\end{array} = H_2SO_4 + C_2H_4.$$

Sulphuric acid may be replaced, with advantage, by syrupy phosphoric acid, because no charring occurs when this acid is employed. The ethylene is evolved when alcohol is slowly dropped into the acid which is heated to 200–220° (C. 1901, II. 177).

(6) By the electrolysis of a concentrated solution of potassium succinate (see ethane) (*Kekulé*):



$$\overbrace{\begin{array}{l}CH_2\vdots CO_2\\ |\qquad\vdots\\ CH_2\vdots CO_2\end{array}}^{+}\overbrace{\begin{array}{|l}K\quad HO\vdots\\ \ +\qquad\ \vdots\\ K\quad HO\vdots\end{array}}^{-}\overbrace{\begin{array}{l}H\\ \\ H\end{array}\begin{array}{l}CH_2\\ =\|\\ CH_2\end{array}}^{+} + 2CO_2 + 2KOH + \overbrace{\begin{array}{l}H\\ |\\ H\end{array}}^{-}.$$

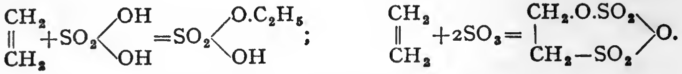
Ethylene is a colourless gas, with a peculiar, sweetish odour. Water dissolves but small quantities of it, whilst alcohol and ether absorb about 2 volumes. It is liquefied at 0°, at a pressure of 42 atmospheres. Its critical temperature is 13°, and its critical pressure exceeds 60 atmospheres. It is suitable for the production of very low temperatures (B. **32**, 49). It burns with a bright, luminous flame, decomposing initially into methane and acetylene (B. **27**, R. 459). A mixture of ethylene and chlorine when ignited burns slowly with a very sooty flame. It forms a strongly explosive mixture with oxygen (3 volumes).

(1) In the presence of platinum black, it will combine with hydrogen at ordinary temperatures, yielding C_2H_6 (B. **7**, 354).

(2) It is absorbed by concentrated hydrobromic and hydriodic acids at 100°, with the production of C_2H_5Br and C_2H_5I:

$$\begin{array}{l}CH_2\\ \|\\ CH_2\end{array} + H_2 = \begin{array}{l}CH_3\\ |\\ CH_3\end{array}; \qquad \begin{array}{l}CH_2\\ \|\\ CH_2\end{array} + HI = \begin{array}{l}CH_2I\\ \\ CH_3\end{array}.$$

(3) It combines with sulphuric acid at 160–174°, forming ethyl sulphuric acid; and with sulphuric anhydride it yields carbyl sulphate:



$$\begin{matrix}CH_2\\ \|\\ CH_2\end{matrix} + SO_2\Big\langle\begin{matrix}OH\\ OH\end{matrix} = SO_2\Big\langle\begin{matrix}O.C_2H_5\\ OH\end{matrix}; \qquad \begin{matrix}CH_2\\ \|\\ CH_2\end{matrix} + 2SO_3 = \begin{matrix}CH_2.O.SO_2\\ |\\ CH_2-SO_2\end{matrix}\Big\rangle O.$$

(4) It unites readily with chlorine and bromine, as well as with iodine in alcoholic solution, and with the two iodine chlorides (B. **26**, 368):

$$\begin{matrix}CH_2\\ \|\\ CH_2\end{matrix} + Br_2 = \begin{matrix}CH_2Br\\ |\\ CH_2Br\end{matrix}; \qquad \begin{matrix}CH_2\\ \|\\ CH_2\end{matrix} + ClI = \begin{matrix}CH_2Cl\\ |\\ CH_2I\end{matrix}.$$

(5) It forms the monochlorhydrin of glycol by its union with hypochlorous acid.

(6) Ethylene glycol itself, however, is produced by carefully oxidizing ethylene with dilute potassium permanganate, which acts as if hydrogen peroxide added itself to the ethylene:

$$\begin{matrix}CH_2\\ \|\\ CH_2\end{matrix} + ClOH = \begin{matrix}CH_2Cl\\ |\\ CH_2OH\end{matrix}; \qquad \begin{matrix}CH_2\\ \|\\ CH_2\end{matrix} + \begin{matrix}OH\\ |\\ OH\end{matrix} = \begin{matrix}CH_2OH\\ |\\ CH_2OH\end{matrix}.$$

Ethylene combines with mercuric salts in solution forming such compounds as $CH_2(OH).CH_2HgCl$, $ClHgCH_2.CH_2.O.CH_2.CH_2.HgCl$, which can be looked upon as being derivatives of ethylene glycol (B. **34**, 2906).

Ethylene Homologues.—Higher olefines are found in the tar obtained from bituminous shales (B. **28**, 496), in American petroleum (C. 1906, II. 120), and apparently also in coal tar (B. **38**, 1296). Just as ethyl alcohol is the most suitable substance for the preparation of ethylene, so its homologues are the best parent substance for the production of the homologues of ethylene.

Methods of Formation.—(1) The halogen derivatives, readily formed from the alcohols, are digested with alcoholic sodium or potassium hydroxide.

In this reaction the haloid (especially the iodide) derivatives corresponding with the secondary and tertiary alcohols break up very readily (C. 1900, I. 1063). *Propylene* has been obtained from isopropyl iodide, *α-butylene* from the iodide of normal butyl alcohol, *β-butylene* from secondary butyl iodide, and *isobutylene* from the iodide of tertiary butyl alcohol. Many others have been prepared in the same way. Heating with lead oxide effects the same result (B. **11**, 414). Tertiary iodides yield olefines when treated with ammonia.

(2) Distillation of the monohydric alcohols, $C_nH_{2n+1}OH$, with dehydrating agents, *e.g.* sulphuric acid, zinc chloride, and phosphorus pentoxide (C. 1901, II. 77), or boron trioxide or oxalic acid (C. 1898, I. 557; B. **34**, 3249) causes the removal of one molecule of water, and, thereby, the production of the corresponding olefine. Isomeric and polymeric forms are produced together with the normal olefines.

The secondary and tertiary alcohols decompose particularly readily. The higher alcohols, not volatile without decomposition, undergo the above change when heat is applied to them; thus cetene, $C_{16}H_{32}$, is formed on distilling cetyl alcohol, $C_{16}H_{34}O$.

When sulphuric acid acts on the alcohols, acid esters of sulphuric acid (the so-called acid ethereal salts—see these) appear as intermediate products. When heated they break down into sulphuric acid and C_nH_{2n} hydrocarbons (comp. ethylene).

The higher olefines may be obtained from the corresponding alcohols by distilling the esters they form with the fatty acids. The products are an olefine and an acid (B. **16**, 3018):

$$\underset{\text{Dodecyl Ester of Palmitic Acid.}}{C_{15}H_{31}CO_2C_{12}H_{25}} = \underset{\text{Palmitic Acid.}}{C_{15}H_{31}CO_2H} + \underset{\text{Dodecylene.}}{C_{12}H_{24}}.$$

Also, xanthogenic acid ester decomposes at relatively low temperatures into olefines, carbon oxysulphide and mercaptans (B. **32**, 3332).

(3) Halogen addition products of the olefines (see ethylene) react with metals to form free olefines.

(4) By heating alkyl ammonium phosphates (B. **34**, 300).

(5) The electrolysis of the potassium salts of saturated dicarboxylic acids (see ethylene) results, as follows: glutaric acid yields propylene (C. 1904, II. 823).

(6) When zinc alkyls act on bromo-olefines, the olefines are liberated, *e.g.* $CH_2{=}CHBr$, which with zinc ethyl yields α-butylene or ethyl ethylene.

(7) Higher olefines have also been obtained by the reaction of *Würtz* (p. 75).

(8) The formation of higher alkylenes by the linking of lower members with tertiary alcohols or alkyl iodides, is noteworthy. Thus, from tertiary butyl alcohol and isobutylene, by means of zinc chloride or sulphuric acid, isodibutylene is obtained (A. **189**, 65; B. **27**, R. 626):

$$(CH_3)_3C.OH + CH_2:C(CH_3)_2 = \underset{\text{Isodibutylene.}}{(CH_3)_3C.CH:C(CH_3)_2} + H_2O.$$

The action of the $ZnCl_2$ is due to the intermediate formation of addition products, *e.g.* trimethyl ethylene and zinc chloride unite to the crystalline compound $(CH_3)_2C{=}CHCH_3,2ZnCl_2$. Water converts this into dimethyl ethyl carbinol, whilst hydrogen chloride produces the chloride of the latter. This chloride and trimethyl ethylene then unite to form a saturated chloride, which, on distillation, splits off hydrochloric acid and yields diamylene (B. **25**, R. 865); see also polymerization of olefines.

Tetramethyl ethylene (B **16**, 398) is produced by heating β-isoamylene (see p. 85) with methyl iodide and lead oxide:

$$(CH_3)_2C:CH.CH_3 + CH_3I = (CH_3)_2C:C(CH_3)_2 + HI.$$

In the dry distillation of many complicated carbon compounds the olefines are produced together with the normal paraffins, hence their presence in illuminating gas and in tar oils (see ethylene).

Properties and Reactions of the Olefines.—So far as physical properties are concerned, the olefines resemble the normal hydrocarbons; the lower members are gases, the intermediate ethereal liquids, whilst the higher (from $C_{16}H_{32}$ upwards) are solids. Generally, their boiling points are a few degrees higher than those of the corresponding paraffins.

In chemical properties, on the other hand, they differ greatly from the paraffins. Being unsaturated, they can unite directly with two univalent atoms or groups, whereby the double bond becomes single.

They combine:

(1) With nascent hydrogen, forming paraffins with a like number of carbon atoms (see ethylene).

(2) With HBr and, with especial readiness, with HI.

The halogen acids attach themselves in such a manner to the mono- and dialkyl ethylenes that the halogen unites with the carbon atom combined with fewest hydrogen atoms (B. **39**, 2138). As such alkylized ethylenes can be prepared from the proper primary alcohols by the splitting-off of water, these reactions can be employed to convert primary into secondary alcohols, and also tertiary alcohols (p. 107).

The olefines are also capable of combining with the fatty acids (B. **25**, R. 463), but only when exposed to high temperatures ($290–300^{\circ}$), *e.g.*:

$$C_5H_{11}CH{=}CH_2+CH_3.CO_2H{=}C_5H_{11}CH(O.CO.CH_3).CH_3.$$

Pentyl Ethylene. Sec.-Heptyl Acetate.

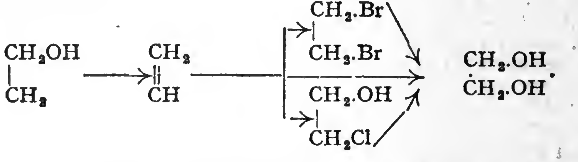
(3) Concentrated sulphuric acid absorbs them, forming ethereal salts. This is a reaction which can be used to convert olefines into alcohols, and also to separate them from paraffins (see p. 81), which are much more resistant to the action of sulphuric acid (C. 1899, I. 967).

(4) They form dihalides (see ethylene) with Cl_2, Br_2, I_2, ClI. These can be viewed as the haloid esters of the dihydric alcohols—the glycols, into which they can be converted.

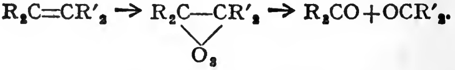
(5) They yield chlorhydrins with aqueous hypochlorous acid. These are the basic esters of the glycols (see ethylene), in which the hydroxyl is attached to the less hydrogenized carbon atom (C. 1901, II. 1249).

(6*a*) Potassium permanganate in dilute solution changes them to glycols (B. **21**, 1230, 3359).

The last three reactions afford a means of converting monacid (monohydric) alcohols into dihydric alcohols or glycols (*q.v.*). The olefines take an intermediate part in these changes, *e.g.*:



(6*b*) Energetic oxidation severs the double bond of the olefines. Ozone, O_3, becomes added at the double bond to form *ozonides*, which are decomposed by water into two molecules of aldehydes or ketones (A. **343**, 311):



$$R_2C{=}CR'_2 \rightarrow R_2\underset{O_3}{C{-}CR'_2} \rightarrow R_2CO+OCR'_2.$$

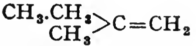
(7) N_2O_3 and N_2O_4 convert the olefines into *nitrosites* and *nitrosates* (*q.v.*). They are the nitrites and nitrates of oximes of hydroxyaldehydes and hydroxyketones. The olefines can even take up nitrosyl chloride (B. **12**, 169; **27**, 455, R. 467; C. 1901, II. 1201). The resulting addition products are changed by boiling water, alcoholic potassium hydroxide, and ammonia back into the olefines (B. **29**, 1550).

(8) *Polymerization of Olefines.*—When acted on by dilute sulphuric acid (B. **29**, 1550), zinc chloride (C. 1897, I. 360), boron fluoride, and other substances, many olefines undergo polymerization even at ordinary temperatures, in consequence of the union of several molecules. Thus, there result from isobutylene,

C_4H_8: di-isobutylene, C_8H_{16}; from isoamylene, C_5H_{10}: di-isoamylene, $C_{10}H_{20}$; tri-isoamylene, $C_{15}H_{30}$, etc. Butylene and propylene behave in the same way. Ethylene, on the other hand, is not condensed by sulphuric acid or by boron fluoride. The polymers act like unsaturated compounds, and contain a pair of doubly linked carbon atoms.

Although ethylene itself undergoes no alteration, yet its unsymmetrical halogen substitution products polymerize very readily (see p. 98).

Below are given the boiling points of some of the homologues of ethylene. It is most convenient to designate them as alkyl substitution products of ethylene.

Propylene	$CH_3CH=CH_2$	$-48°$ gaseous (B. **33**, 638).
Ethyl Ethylene	$CH_3CH_2CH=CH_2$	$-5°$
plane-sym. axial-sym. } Dimethyl Ethylene	$CH_3.CH=CH.CH_3$	$+1°$ $+2·5°$ (p. 80).
unsym. Dimethyl Ethylene . .	$(CH_3)_2C=CH_2$	$-6°$
n.-Propyl Ethylene . . . . α-Amylene	$CH_3CH_2CH_2CH=CH_2$	$+39°$
Isopropyl Ethylene . . . . α-Isoamylene	$(CH_3)_2CH.CH=CH_2$	$+21°$ (C. 1900, I. 1195).
sym. Methyl Ethyl Ethylene . β-Amylene	$CH_3.CH_2.CH=CH.CH_3$	$+36°$
unsym. Methyl Ethyl Ethylene . γ-Amylene	 $\begin{matrix}CH_3.CH_2\\CH_3\end{matrix}\!>C=CH_2$	$+31°$
Trimethyl Ethylene . . . . β-Isoamylene	$(CH_3)_2C=CH.CH_3$	$+36°$
Tetramethyl Ethylene . . .	$(CH_3)_2C=C(CH_3)_2$	$+73°$ (B. **27** 454).

Many other higher members of this series are known. Of these, trimethylethylene or β-isoamylene, *pental*, possesses a significance, as it is used in the preparation of the so-called *amylene hydrate* or tertiary amyl alcohol. β-Isoamylene constitutes the chief ingredient of the mixture of olefines resulting from the action of zinc chloride on the amyl alcohol of fermentation (A. **190**, 332 ; B. **36**, 2003). The formation of tetramethyl ethylene from pinacolyl alcohol or methyl-tert.-butyl carbinol is of interest because it appears to be a reversal of the formation of pinacolin from pinacone (*q.v.*) (B. **24**, 3251, footnote). Both tri- and tetramethyl ethylene can be prepared from amylene hydrate and pinacolyl alcohol respectively, by heating them with anhydrous oxalic acid.

HYDROCARBONS, C_nH_{2n-2}

Two groups of hydrocarbons having this empirical formula exist:

The *acetylenes* or alkines with triple linking, and

The *allylenes* with two double linkages.

The allylenes are also called *diolefines*. The difference in structure is clearly shown in their different chemical behaviour. The acetylenes (with group≡CH) alone have the power of entering into combinations in which the hydrogen of the group≡CH is replaced by metals. The names adopted for the acetylenes by the Geneva Congress are formed by substituting the ending "ine" for the ending *yl* of alcohol radicals with like carbon content, hence the designation *alkines*.

2. ACETYLENES OR ALKINES, C_nH_{2n-2}

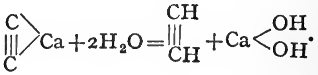
The position of acetylene, the first member of this series, among the aliphatic hydrocarbons is very prominent, on account of its technical importance, and its direct formation from carbon and hydrogen. Some acetylenes are distinguished by their *power of polymerization*, which result in the formation of simple *aromatic hydrocarbons*.

Acetylene [*Ethine*] $CH{\equiv}CH$ was first observed by ***Edmund Davy.*** *Berthelot* introduced the name acetylene and studied the hydrocarbon carefully.

(1) *Berthelot* effected the synthesis of acetylene by passing the electric spark between carbon points in an atmosphere of hydrogen (p. 64):

$$2C+H_2=CH{\equiv}CH.$$

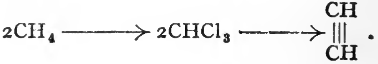
(2) It results in the decomposition of the carbides of the alkali earths by water (B. **25,** R. 850; **27,** R. 297):



$$\begin{array}{c}C\\ |||\\ C\end{array}\!\!>Ca+2H_2O=\begin{array}{c}CH\\ |||\\ CH\end{array}+Ca<\begin{array}{l}OH\\ OH\end{array}.$$

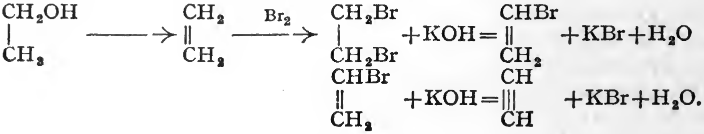
The addition of formaldehyde solution retards the evolution of acetylene from calcium carbide (C. 1900, II. 1150). The gas is always contaminated by phosphine, which can be removed by the action of bromine water, or better by means of a feebly acid solution of copper sulphate and of chromic acid in sulphuric acid (C. 1900, I. 789; B. **32,** 1879). On a large scale bleaching powder or bleaching powder and lead chromate (to avoid the evolution of free chlorine) are recommended as purifiers (C. 1900, I. 236; II. 229). Metal gas holders for use with acetylene are best avoided (C. 1900, I. 954). The gas is employed to an ever-increasing extent for illumination and for cutting and melting metals (by means of the oxygen-acetylene flame).

(3) It may be prepared from methane by converting it into chloroform, from which chlorine is removed by means of red hot copper or heated metallic sodium (*Fittig*). Bromoform, $CHBr_3$ (B. **25,** R. 108), and iodoform, CHI_3, are very readily changed by silver or zinc dust into acetylene:



$$2CH_4 \longrightarrow 2CHCl_3 \longrightarrow \begin{array}{c}CH\\ |||\\ CH\end{array}.$$

(4) Formerly acetylene was always made from ethylene bromide by the action of alcoholic potassium hydroxide (A. **191,** 268). At first the ethylene bromide loses a molecule of hydrogen bromide and becomes monobromethylene or vinyl bromide, which in turn loses a molecule of hydrogen bromide with the production of acetylene:



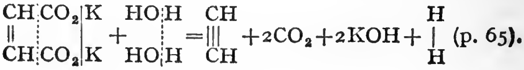
$$\begin{array}{l}CH_2OH\\ |\\ CH_3\end{array}\longrightarrow\begin{array}{l}CH_2\\ \|\\ CH_2\end{array}\xrightarrow{Br_2}\begin{array}{l}CH_2Br\\ |\\ CH_2Br\end{array}+KOH=\begin{array}{l}CHBr\\ \|\\ CH_2\end{array}+KBr+H_2O$$

$$\begin{array}{l}CHBr\\ \|\\ CH_2\end{array}+KOH=\begin{array}{l}CH\\ |||\\ CH\end{array}+KBr+H_2O.$$

As ethylene is invariably obtained from ethyl alcohol and sulphuric acid, this method allies acetylene genetically with ethyl alochol.

Acetylene is also formed when quarternary piperazonium salts (*q.v.*) are boiled with sodium hydroxide solution (B. **37,** 3507).

(5) Acetylene is also produced by the electrolysis of the alkali salts of the two isomeric dicarboxylic acids—maleïc and fumaric (*Kekulé*, A. **131,** 85):



$$\begin{array}{l}CH\,CO_2|K\\ \|\\ CH\,CO_2|K\end{array}+\begin{array}{l}HO\,H\\ \\ HO\,H\end{array}=\begin{array}{c}CH\\ |||\\ CH\end{array}+2CO_2+2KOH+\begin{array}{c}H\\ |\\ H\end{array}\text{ (p. 65).}$$

(6) Acetylene is given off when sodium hydroxide solution acts on propargyl aldehyde:

$$CH{\equiv}C-CHO+HONa=CH{\equiv}CH+CHOONa.$$

(7) It is worthy of note that potassium acetylene-monocarboxylate and silver acetylene-dicarboxylate are readily converted, when warmed with water, into carbon dioxide and acetylene, and silver acetylide respectively (A. **272**, 139). The stability of the dicarboxylic acids is very much influenced by the manner of union of the carbon atoms, to which the carboxyl groups are attached.

$$AgO_2C.C{\equiv}C.CO_2Ag=AgC{\equiv}CAg+2CO_2.$$

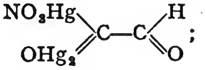
Acetylene is further formed when many carbon compounds, like alcohol, ether, methane, ethylene, etc., are exposed to intense heat (their vapours conducted through tubes heated to redness). Hence it is present in small amount in illuminating gas, to which it imparts a peculiar odour.

Properties.—Pure acetylene is a gas of ethereal, agreeable odour, and may be liquefied at +1° and under a pressure of 48 atmospheres. It solidifies when rapidly vaporized and then sublimes at −82° (B. **33**, 638). It is a strongly endothermic compound, of which the heat of formation is −61 Cal. It is slightly soluble in water; more readily in alcohol and ether, and easily in methylal, acetal, ethyl acetate, and *acetone* (C. 1897, I. 800). It burns with a very smoky flame, and with air (9 vols.), but especially with oxygen (2½ vols.), forms an exceedingly explosive mixture (*Anschütz*). Under certain conditions acetylene decomposes with generation of heat and sudden increase in volume. When subjected to high pressure, and especially when liquefied this decomposition is extremely dangerous (C. 1897, II. 332; 1899, I. 1018).

Reactions.—Nascent hydrogen converts acetylene into C_2H_4 and C_2H_6. Ordinary hydrogen (2 vols.) and acetylene (1 vol.), passed over platinum black, form C_2H_6 (B. **7**, 352). Finely divided Ni, Co, Fe, and Cu behave similarly (C. 1899, I. 1270; 1900, II. 528), producing at the same time high molecular cork-like condensation products (B. **32**, 2381). Acetylene combines with HCl and HI, forming CH_3CHCl_2 and CH_3CHI_2.

Acetylene reacts with chlorine gas in the sunlight with a slight explosion. It forms a crystalline compound with $SbCl_5$, which is changed by heat into dichlorethylene, CHCl : CHCl, and $SbCl_3$. With bromine it forms $C_2H_2Br_2$ and $C_2H_2Br_4$ (A. **221**, 138).

In contact with $HgBr_2$ and other mercury salts acetylene unites with water to yield ***aldehyde***, which is also produced when acetylene alone is heated with water to 325°, or when it is passed into dilute sulphuric acid in presence of HgO (C. 1898, II. 1007). Fuming sulphuric acid absorbs acetylene, forming acetaldehyde di-sulphonic acid and methionic acid (*q.v.*). With HClO and HBrO acetylene forms dichlor- and dibromacetaldehyde (C. 1900, II. 29). Acetylene unites with an aqueous solution of mercuric nitrate to form a substance—



$$\begin{matrix}NO_3Hg\\OHg_2\end{matrix}\!\!>C-C\!\!<\!\!\begin{matrix}H\\O\end{matrix};$$

which can also be obtained from acetaldehyde; similarly, trichloromercuriacetaldehyde $(ClHg)_3C.CHO$ is produced with mercuric chloride solution (B. **37**, 4417). In the case of mercuric nitrite or chlorate, however, the similar compounds which are formed, are explosive (B. **38**, 1999). In diffused daylight, contact with potassium hydroxide solution and air, acetylene changes into acetic acid. Oxydation with nitric acid leads to the formation of nitroform $CH(NO_2)_3$, and other bodies (C. 1901, II. 177). Acetylene unites with diazomethane, producing pyrazole (see Vol. II.).

Acetylene polymerizes at a red heat, three molecules uniting to form one molecule of *benzene*, C_6H_6. This is one of the most striking transitions from the aliphatic to the aromatic series and, at the same time, constitutes a synthesis of the parent hydrocarbon of aromatic substances (*Berthelot*).

This conversion will take place at the ordinary temperature if acetylene be passed over pyrophoric iron, nickel, cobalt, or platinum sponge (B. **29**, R. 540; see also above).

Metallic Derivatives of Acetylene.—The two hydrogen atoms of acetylene can be replaced by metals. The alkali and alkali earth acetylides are stable even when heated, but are decomposed by water with the liberation of acetylene. Copper and silver acetylides when dry are exceedingly explosive, but are stable in the presence of water. Acids evolve pure acetylene from them.

Sodium Acetylides, $CH{\equiv}CNa$ and $CNa{\equiv}CNa$ are produced when sodium is heated in acetylene gas (C. 1897, I. 966; 1899, I. 174; 1904, II. 1204). **Calcium Acetylide** or **Calcium Carbide,** C_2Ca, is formed when calcium oxide is reduced by carbon at a red heat (*Wöhler*, 1862), and when a mixture of *calcium oxide* and *sugar carbon* is heated in electric furnaces to 3500° (*Moissan*, B. **27**, R. 238; C. 1899, II. 1093). It is a homogeneous mass, colourless in its purest form but usually obtained of a grey tint, and shows a crystalline fracture. If fragments of calcium carbide are dropped into a tall glass cylinder filled with saturated chlorine water, the liberated acetylene will combine with the chlorine with the production of flame. Gas-bubbles, giving out light, rise in the liquid and when they reach the surface burn there with a smoky flame **Lithium Carbide,** C_2Li_2, is obtained from lithium carbonate and carbon (B. **29**, R. 210). **Cæsium Carbides,** C_2HCs and C_2Cs_2, and **Rubidium Carbides,** C_2HRb and C_2Rb_2, are produced when acetylene is led into solutions of cæsium-ammonium and rhubidium-ammonium in ammonia (C. 1903, II. 105).

Silver Acetylide, C_2Ag_2, a white precipitate, and **Copper Acetylide,** C_2Cu_2 (B. **25**, 1097; **26**, R. 608; **27**, R. 466), a red precipitate, are formed when acetylene is conducted into ammoniacal silver or cuprous chloride solutions. The dry salts explode violently when they are heated; the silver salt even does this when gently rubbed with a glass rod. In a solution of silver nitrate acetylene precipitates the compound $HC{\equiv}CAg.AgNO_3$ (B. **28**, 2108). **Gold Acetylide,** C_2Au_2, a yellow precipitate, is obtained from acetylene and a solution of ammoniacal gold-sodium thiosulphate (C. 1900, I. 755). Pure acetylene is set free by acids from these metallic compounds. The copper salt serves for the detection of acetylene in a mixture of gases. **Mercury Acetylide,** C_2Hg, is thrown out as a white precipitate from alkaline solutions of mercuric oxide. It explodes violently when heated rapidly.

Acetylene Homologues.—The diolefines are isomeric with the homologues of acetylene. They contain a like number of carbon atoms, *e.g.* allene, $CH_2{=}C{=}CH_2$, is isomeric with methyl acetylene (allylene) $CH_3.C{\equiv}CH$; divinyl, $CH_2{:}CH.CH{:}CH_2$, with dimethyl acetylene (crotonylene), $CH_3.C{:}C.CH_3$.

The higher homologues, just like acetylene, are mostly prepared from the mono-halogen and di-halogen substitution products of the olefines, the *olefine dibromides*, by the action of alcoholic potassium hydroxide, *e.g.* from $CH_3CCl{=}CH_2$: *allylene;* from $CH_3.CHBr.CHBr.CH_3$:

crotonylene, $CH_3C{\equiv}C.CH_3$. In this manner a host of higher acetylene homologues have been prepared from the dibromides of the higher olefines (B. **33**, 3586). Alkines are also obtained by the action of alcoholic potassium hydroxide on aldehydic and ketonic chlorides, *e.g.* œnanthylidene chloride yields œnanthylidene $CH_3[CH_2]_4C{\equiv}CH$ (C. 1900, II. 1231).

When strongly heated with alcohol the acetylene formed frequently undergoes a *transposition*; thus, ethyl acetylene, $C_2H_5.C{\equiv}CH$, yields dimethyl acetylene, $CH_3.C{\equiv}C.CH_3$, and propyl acetylene, $C_3H_7.C{\equiv}CH$, furnishes ethyl methyl acetylene, $C_2H_5.C{\equiv}C.CH_3$, etc. (B. **20**, R. 781). Symmetrically constituted bodies may be formed from unsymmetrical compounds.

The reverse transposition sometimes occurs on heating with metallic sodium; ethyl methyl acetylene passes into propyl acetylene, and dimethyl allene, $(CH_3)_2C{=}C{=}CH_2$, yields isopropyl acetylene, etc. (B. **21**, R. 177).

Acetylenes are also formed in the electrolysis of unsaturated dibasic acids: thus, *allylene* is formed in the electrolysis of the alkali salts of mesaconic and citraconic acids.

Acetylene and its homologues unite with hydrogen to form olefines, which in turn pass into paraffins. By the addition of halogen acids or the halogens mono- and di-haloid olefines are formed. The further addition of halogen acids and halogens to these yields di-, tri-, and tetra-halogen substitution products of the paraffins.

Hypochlorous and hypobromous acids convert the alkines into dichloro- and dibromo-ketones, *e.g.* allylene $CH_3.C{\equiv}CH$ with HBrO yields asymmetric dibromacetone (C. 1900, II. 29); also, methyl ethyl acetylene $C_2H_5C{\equiv}C.CH_3$ with 2HClO gives α-dichloropropyl methyl ketone $CH_3CH_2CCl_2.CO.CH_3$ (B. **28**, R. 781). When heated with water to 325°, the alkyl acetylenes yield ketones (B. **27**, R. 750; **28**, R. 173).

A characteristic of all mono-alkyl acetylenes, as well as of acetylene itself, is their power to yield solid crystalline compounds by the action of ammoniacal solutions of silver and cuprous salts, from which they can be regenerated by warm hydrochloric acid. This behaviour affords a very convenient method for separating the acetylenes from other gases, and obtaining them in a pure condition.

The acetylenes are absorbed by concentrated sulphuric acid; some even polymerize to aromatic derivatives.

In the presence of $HgBr_2$ and other salts of mercury, the acetylenes unite with water: acetylene yields aldehyde, C_2H_4O; allylene, C_3H_4, acetone, C_3H_6O; valerylene, C_5H_8, a ketone, $C_5H_{10}O$ (B. **14**, 1540, and **17**, 28). Very often moderately dilute sulphuric acid will act in the same way; methyl n-propyl acetylene gives two isomeric ketones when treated with approximately 8 per cent. sulphuric acid.

The boiling points of some of the acetylenes are as follows:—

		B.P.
Allylene, Methyl Acetylene [Propine]	$CH_3C{\equiv}CH$	Gas
Crotonylene, Dimethyl Acetylene [2-Butine] . . .	$CH_3C{\equiv}CCH_3$	27°
Ethyl Acetylene [3-Butine]	$C_2H_5C{\equiv}CH$	18°
Methyl Ethyl Acetylene [3-Pentine]	$C_2H_5C{\equiv}CCH_3$	55°
n.-Propyl Acetylene [4-Pentine]	n-$C_3H_7C{\equiv}CH$	48°
Isopropyl Acetylene [3-Methyl-1-Butine] . . .	$(CH_3)_2CH.C{\equiv}CH$	28°
Methyl n.-Propyl Acetylene [4-Hexine]	n-$C_3H_7C{\equiv}C.CH_3$	84°

Allylene and *crotonylene* deserve consideration, because, when brought into contact with concentrated sulphuric acid, they pass into symmetric *trimethylbenzene* and *hexamethyl-benzene.*

$$3CH_3C{\equiv}CH \longrightarrow C_6H_3[1,3,5](CH_3)_3\text{—Mesitylene.}$$

$$3CH_3C{\equiv}CCH_3 \longrightarrow C_6(CH_3)_6\text{—Hexamethyl Benzene.}$$

Interaction between sodium alkines and acid chlorides produces the alkine ketones; *e.g.* sodium œnanthylidene and acetyl chloride yield œnanthylidene methyl ketone $CH_3[CH_2]_4C{\equiv}C.CO.CH_3$. Sodium alkines and trihydroxy methylene give sodium alcoholates $RC{\equiv}CCH_2OH$. CO_2 combines with the sodium alkines forming acetylene carboxylic acids: sodium acetylene gives sodium propiolate $CH{\equiv}C.COONa$.

On the higher alkyl acetylenes, see B. **25**, 2245; **33**, 3586.

3. DIOLEFINES, C_nH_{2n-2}

The diolefines are not capable of forming silver and copper compounds, but give precipitates with mercuric sulphate and chloride in aqueous solution (B. **21**, R. 185, 717; **24**, 1692).

The "Geneva names" for the diolefines are derived by inserting a "di," for the number of double linkages, before the final syllable "ene"—*e.g.* [propadiëne] for symmetric allylene.

The diolefines are prepared by splitting off hydrobromic acid from the paraffin dibromides by means of alcoholic potassium hydroxide, pyridine or quinoline; as well as by heating the diamine phosphates (B. **34**, 300).

Diolefines with a "conjugated double binding"—$CH{=}CH.CH{=}CH$—often add bromine or hydrogen in the 1,4 position; *e.g.* butadiëne gives 1,4-dibromobutene $BrCH_2.CH{=}CH.CH_2Br$.

Ozone unites with the diolefines forming diozonides, of which the decomposition (p. 84, 6b), caused by water, assists in the elucidation of its constitution. Atmospheric oxygen is also absorbed with greater or less ease by diolefines. On polymerization, see B. **35**, 2130, etc.

Of the numerous hydrocarbons of this class some are worthy of note because of their genetic relations. They are:

Allene, sym. Allylene [Propadiëne]	$CH_2{=}C{=}CH_2$	Gas
Divinyl, Erythrene [1,3-Butadiëne] Pyrrolylene	$CH_2{=}CH{-}CH{=}CH_2$	B.P.—5°
Piperylene, α-Methyl Butadiëne	$CH_2{=}CH{-}CH{=}CH{-}CH_3$	,, 42°
Isoprene, β-Methyl Butadiëne	$CH_2{=}CH{-}C(CH_3){=}CH_2$	,, 35°
Di-isopropenyl, βγ-Dimethyl Butadiëne	$CH_2{=}C(CH_3){-}C(CH_3){=}CH_2$	,, 71°
1,1,3-Trimethyl Butadiëne	$(CH_3)_2C:CH.C(CH_3):CH_2$	,, 93°
Diallyl [1,5-Hexadiëne]	$CH_2{=}CH{-}CH_2{-}CH_2{-}CH{=}CH_2$	,, 59°
2,5-Dimethyl-1,5-Hexadiëne	$CH_2{=}C(CH_3).CH_2.CH_2.C(CH_3){=}CH_2$	,, 137°
1,1,5-Trimethyl-1,5-Hexadiëne	$(CH_3)_2C:CH.CH_2.CH_2.C(CH_3){=}CH_2$	,, 141°
Conylene [1,4-Octadiëne]	$CH_2{=}CH{-}CH_2{-}CH{=}CH{-}CH_2CH_2CH_3$	,, 126°

Allene is obtained by electrolysis of potassium itaconate (p. 515); also by heating bromomethyl acrylic acid, and by decomposition of dibromopropylene $CH_2Br.CHBr:CH_2$ by zinc dust. Contrary to allylene, it is not absorbed by ammoniacal silver nitrate, but, like it, gives the same white mercury precipitate, which is decomposed by acids, yielding acetone (A. **342**, 185).

Divinyl, Erythrene, or **Pyrrolylene** is found in compressed illuminating gas, and serves as the parent substance for the synthesis of erythritol, from which it results on boiling with formic acid. It is called pyrrolylene because it is formed in the breaking down of pyrrolidine or tetrahydropyrrole (Vol. II.) (B. **19**, 569; A, **308**, 333).

Piperylene and **Conylene** are formed in the same manner from piperidine (Vol. II.) and coniine (Vol. II.) (B. **14**, 665, 710; A. **319**, 226). Piperylene is also produced from 2,4-dibromopentane by the abstraction of 2HBr by quinoline (C. 1901, II. 183).

Isoprene, a distillation product of caoutchouc, is closely related to the terpenes. It is called a *hemiterpene*, and by spontaneous polymerization passes into dipentene or cinene (Vol. II.), and then back into caoutchouc (B. **25**, R. 644). This latter change can be accelerated by the catalytic action of a number of substances, notably metallic sodium.

1,1,3-**Trimethyl-butadiëne** is obtained from mesityl oxide by methyl magnesium iodide, when water is split off from the olefine alcohol first produced (B. **37**, 3578).

1,1,5-**Trimethyl**-1,5-**hexadiëne** is similarly produced from methyl heptenone. Its diozonide (p. 90) on decomposition yields lævulinic aldehyde (A. **343**, 362).

2,5-**Dimethyl**-1,5-**hexadiëne** is obtained, together with an isomeric hydrocarbon, from 2,5-dimethyl-2,5-dibromohexane; its diozonide yields formaldehyde and acetonylacetone (A. **343**, 365).

Diisopropenyl is obtained from tetramethyl ethylene dichloride (from HCl and pinakone) and alcoholic potassium hydroxide (C. 1900, II. 1061).

Diallyl results from the action of sodium on allyl iodide; its ozonide yields succinic aldehyde (A. **343**, 360).

4. OLEFINE ACETYLENES

By this name are understood the hydrocarbons containing both doubly and trebly linked pairs of carbon atoms in their molecules. Many of them are known, but none deserve special consideration.

5. DIACETYLENES, C_nH_{2n-6}

Diacetylene, $HC \vdots C.C \vdots CH$, is formed from diacetylene dicarboxylic acid. It is a gas that yields a yellow precipitate with an ammoniacal silver solution. The two hydrocarbons, dipropargyl and dimethyl di-acetylene, are isomeric with benzene.

Dipropargyl, $CH \vdots C.CH_2.CH_2.C \vdots CH$, b.p. 85°, is formed on warming solid crystalline diallyl tetrabromide, $C_6H_{10}Br_4$, with aqueous potassium hydroxide. It is a very mobile liquid, of penetrating odour. It forms copper and silver derivatives. If dipropargyl be allowed to stand, it becomes resinous.

Dimethyl Di-acetylene, $CH_3.C\equiv C.C\equiv C.CH_3$, m.p. 64°; b.p. 130°, has been obtained from the copper derivative of allylene (B. **20**, R. 564).

6. TRIOLEFINES, C_nH_{2n-6}

1,1,5,5-**Tetramethyl**-4-**methene**-1,4-**pentadiëne**, $(CH_3)_2C{=}CH.C({:}CH_2).CH{:}C(CH_3)_2$, b.p.$_{14}$ 55–57°, is prepared from phorone and methyl magnesium iodide (B. **37**, 3578).

II. HALOGEN DERIVATIVES OF THE HYDROCARBONS

The halogen substitution products result from the replacement of hydrogen in the hydrocarbons by the halogens. The number N of substitution products in the normal saturated hydrocarbons, containing an even number of *n* carbon atoms, can be calculated by the formula:

$$^{*}N=8\times3^{n-2}+2\times3^{\frac{n-2}{2}}$$

and when *n* is odd:

$$^{*}N=8\times3^{n-2}+2\times3^{\frac{n-1}{2}}.$$

in which the unsubstituted hydrocarbon itself is counted.

If $n=2$, then $N=10$; if $n=3$, then $N=30$; if $n=4$, then $N=78$;
$n=5$ $N=234$ $n=6$ $N=666$ $n=7$ $N=1998$.

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* For these formulæ, the author expresses his thanks to Herr Geheimrath A. V. *Baeyer*, of Munich.

Thus 9 chlorine substitution products can be derived from ethane.

In the discussion of the methods of formation and the reactions of the saturated and unsaturated aliphatic hydrocarbons, their haloid derivatives were constantly encountered. We have also learned the methods of producing these alkylogens, proceeding from the hydrocarbons. They are:

(1) *Formation by the direct substitution of the saturated hydrocarbons.* It was emphasized in the case of methane (p. 72) and ethane (p. 74) that these hydrocarbons, usually so very stable, were attacked by chlorine. A molecule of hydrogen chloride is produced for every hydrogen atom replaced by chlorine, until the entire hydrogen content is substituted. Methane, CH_4, yields finally tetra- or perchloromethane, CCl_4, whilst ethane gives hexa- or perchlorethane, C_2Cl_6.

The action of free chlorine on the paraffins is accelerated by sunlight, as is the case when it acts on free hydrogen (Inorg. Ch.); by the so-called chlorine carriers, such as iodine, which exerts its influence by the formation and decomposition of ICl_3 (Inorg. Ch.); by the similar behaviour of $SbCl_5$ which decomposes by heat into $SbCl_3$ and Cl_2; and by $AlCl_3$ (C. 1900, II. 720), etc. In very energetic chlorination the carbon chain is ruptured (B. **8**, 1296; **10**, 801).

The final products are CCl_4 and hexa- or perchlorobenzene, C_6Cl_6, with perchlorethane, C_2Cl_6, and perchloromesole, C_4Cl_6, as intermediate products (B. **24**, 1011).

The substituting action of bromine may be accelerated by heat, sunlight, or $AlBr_3$ (C. 1900, II. 720).

Iron is an excellent carrier of chlorine, bromine, and iodine. Its action seems to be due to the formation and decomposition of compounds with ferric halides (A. **225**, 196; **231**, 158). When it is used as a bromine carrier, every normal hydrocarbon passes into that bromide which contains just as many bromine atoms as it has carbon atoms (B. **26**, 2436); a bromine atom attaches itself to each carbon atom.

Usually iodine does not substitute well, inasmuch as the final iodine products undergo reduction through the hydriodic acid formed simultaneously with them:

$$C_3H_7I + HI = C_3H_8 + I_2.$$

In the presence of substances capable of uniting or decomposing HI (like HIO_3 and HgO), iodine frequently effects substitution:

$$5C_3H_8 + 2I_2 + HIO_3 = 5C_3H_7I + 3H_2O$$
$$2C_3H_8 + 2I_2 + HgO = 2C_3H_7I + H_2O + HgI_2.$$

In direct substitution a mixture of mono- and poly-substitution products generally results, and these are separated by fractional distillation or crystallization. The attack of chlorine on a long paraffin chain, *e.g.* n-hexane, is directed against the CH_2 groups before the CH_3 (B. **39**, 2138).

(2) Mono- and polychloroparaffins can be converted into mono- and polybromoparaffins by means of $AlBr_3$ (C. 1901, I. 878). Among the bromoparaffins the bromine can be replaced partially by fluorine by means of SbF_3 (C. 1899, II. 281; 1901, II. 804). Boiling with an alcoholic solution of an alkali iodide causes a partial replacement of the halogens in the chloro- or bromo-paraffins (B. **39**, 1951).

(3) The unsaturated aliphatic hydrocarbons, the olefines (p. 84), and acetylenes (p. 87), unite with hydrochloric, hydrobromic, and, especially easily, hydriodic acid. The halogen acids can be used in a glacial acetic acid (B. **11**, 1221), or concentrated aqueous solution.

(4) The free halogens are still more easily absorbed than their acids (p. 84).

Two further reactions, already indicated above, bring about halogen substitution products from aliphatic bodies containing oxygen:

(5) Substitution of the hydroxyl group in alcohols by fluorine, chlorine, bromine, and iodine by means of their halogen acids, or their compounds with phosphorus (p. 132).

(6) Action of phosphorus pentachloride, phosphorus chlorobromide, and phosphorus pentabromide, on aldehydes and ketones.

These last methods of formation will be more thoroughly discussed under the individual groups of halogen substitution products.

Reactions of the Halogen Derivatives.—The reactions which take place among the halogen-paraffin compounds have been referred to under mode of formation (2) (above). The iodine derivatives are the most unstable. In the light they rapidly acquire a red colour, with the separation of iodine. The chlorides and bromides, rich in hydrogen, burn with a green-edged flame (p. 8).

(1) Nascent hydrogen (zinc and hydrochloric acid or glacial acetic acid, sodium amalgam and water) can reconvert all the halogen derivatives, by successive removal of the halogen atoms, into the corresponding hydrocarbons (p. 73):

$$CHCl_3+3H_2=CH_4+3HCl.$$

This change is called a *retrogressive substitution.*

(2) Alcoholic sodium and potassium hydroxides cause the separation of halogen acid, and the production of unsaturated compounds (p. 81):

$$\underset{\text{Propyl Bromide.}}{CH_3.CH_2.CH_2Br}+KOH=\underset{\text{Propylene.}}{CH_3.CH:CH_2}+KBr+H_2O.$$

In this reaction the halogen carries away with it the hydrogen of the least hydrogenized adjacent carbon atom (comp. p. 82). Such a decomposition sometimes occurs on application of heat, and is favoured by the presence of anhydrous metallic chlorides (C. 1905, II. 750).

Many other reactions of the haloid compounds will be discussed later.

A. HALOGEN PARAFFINS

I. MONOHALOGEN PARAFFINS, ALKYL HALIDES

$C_nH_{2n+1}X$

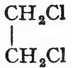
These are genetically connected by reactions with the alcohols, which are almost always employed in their preparation. On comparing the formulæ of the alkylogens with those of the halogen hydrides,

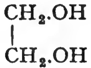
$$\begin{array}{cccc} HF & HCl & HBr & HI \\ C_2H_5F & C_2H_5Cl & C_2H_5Br & C_2H_5I \end{array}$$

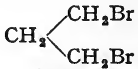
it will be seen that they can be regarded as haloid acids, in which the hydrogen atoms have been replaced by hydrocarbon residues. As the latter, together with the water residue, constitute the monohydric (monacid) alcohols, they are called alcohol radicals or alkyls. Acids, the hydrogen of which is replaceable by metals, yield acid esters when alcohol radicals are substituted for that hydrogen. The monohalogen alkyls are therefore discussed as *haloid esters*, at the head of the acid esters of the monohydroxy-alcohols.

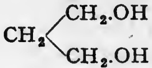
2. DIHALOGEN PARAFFINS, $C_nH_{2n}X_2$

(*a*) Dihalogen paraffins, where two halogen atoms are attached to two different carbon atoms, may be viewed as the haloid esters of dihydroxy-paraffin alcohols or glycols. They can be derived from these and will be considered together with them:

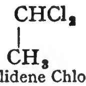

$$\begin{array}{c}CH_2Cl\\ |\\ CH_2Cl\end{array}$$
Ethylene Chloride.

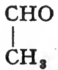

$$\begin{array}{c}CH_2.OH\\ |\\ CH_2.OH\end{array}$$
Ethylene Glycol.

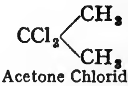

Trimethylene Bromide.

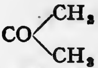

Trimethylene Glycol.

(*b*) Dihalogen paraffins, the two halogen atoms of which are attached to the same carbon atom, may be termed *aldehyde halides*, if the carbon atom is terminal, and *ketone halides*, when the carbon atom occupies an intermediate position. Indeed, these compounds can be obtained from the aldehydes and ketones by means of phosphorus halides. They will, therefore, be discussed after the aldehydes and the ketones:


$$\begin{array}{c}CHCl_2\\ |\\ CH_3\end{array}$$
Ethylidene Chloride Aldehyde Chloride.


$$\begin{array}{c}CHO\\ |\\ CH_3\end{array}$$
Acetaldehyde.


Acetone Chloride β-Dichloropropane.


Acetone.

It should be remarked here that the unsymmetric ethane dihalides —*e.g.* $CH_3.CHCl_2$, ethylidene chloride—have lower boiling points and lower specific gravities than the corresponding symmetric isomers —*e.g.* ethylene chloride, $CH_2Cl.CH_2Cl$.

3. PARAFFIN POLYHALIDES

The paraffin polyhalides, containing but one halogen atom to each carbon atom, will be discussed after the corresponding polyhydric paraffin alcohols.

The simplest and most important representatives of the paraffin trihalides, in which three halogen atoms are attached to the same carbon atom, are the *methane trihalides:*

CHF_3	$CHCl_3$	$CHBr_3$	CHI_3
Fluoroform.	Chloroform.	Bromoform.	Iodoform.

They are so intimately related to formic acid and its derivatives that they will be considered after this acid.

The most important paraffin *tetrahalides* are the *methane tetrahalides*. They bear the same relation to carbonic acid that the methane trihalides do to formic acid. They will, therefore, be treated after carbonic acid:

CF_4	CCl_4	CBr_4	CI_4
Methane Tetrafluoride.	**Methane Tetrachloride.**	**Methane Tetrabromide.**	**Methane Tetraiodide.**

These compounds are also called methane perhalides, to indicate that the hydrogen in them is completely replaced by halogens.

Polyhalide Ethanes.—The following table contains the boiling points of the known polychlor- and polybrom-ethanes:

Name.	Formula.	M.P.	B.P.	Formula.	M.P.	B.P.
Vinyl Trichloride . . . β-Trichlorethane . .	CH_2Cl $\dot{C}HCl_2$	—	114°	$CHBr_2$ $\dot{C}H_2Br$	—	187–188°
Ethenyl Trichloride . . α-Trichlorethane . . Methyl Chloroform .	CCl_3 $\dot{C}H_3$	—	74·5°	—	—	—
sym.-Acetylene Tetrachloride	$CHCl_2$ $\dot{C}HCl_2$	—	147°	$CHBr_2$ $\dot{C}HBr_2$	—	102° (12 mm.)
unsym.-AcetylideneTetrachloride	CCl_3 $\dot{C}H_2Cl$	—	129°	CBr_3 $\dot{C}H_2Br$	—	105° (13·5 mm.)
Pentachlorethane . .	CCl_3 $\dot{C}HCl_2$	—	159°	CBr_3 $\dot{C}HBr_2$	54°	decomposes
Perchlorethane	CCl_3 $\dot{C}Cl_3$	187°	sublimes	CBr_3 $\dot{C}Br_3$	—	decomposes at 200–210° without melting.

For the relations existing between the boiling points and specific volumes of the halogen substitution products of the ethanes, see B. **15**, 2559. As to the refractive power of the brominated ethanes, see Z. phys. Ch. **2**, 236.

The polychlor- and polybrom-ethanes have few genetic relationships with the oxygen compounds corresponding with them. The methods of formation and the reactions of the polysubstituted ethanes are most intimately related to the methods of formation and the reactions of the halogen substitution products of the ethylenes and acetylenes, a tabular view of which will be given in the following section. They will, therefore, precede the discussion of the latter.

It may be merely mentioned here that by the action of chlorine on ethyl chloride and ethylidene chloride in sunlight *methyl chloroform* or *α-trichlorethane*, CH_3CCl_3, is produced, together with *vinyl trichloride*, $CH_2Cl.CHCl_2$. The further action of chlorine on the trichlorethanes produces $CH_2Cl.CCl_3$, $CHCl_2.CCl_3$, and perchlorethane, $CCl_3.CCl_3$. $CHCl_2.CHCl_2$ is formed from acetylene dichloride and chlorine, as well as from dichloraldehyde by means of phosphorus pentachloride (B. **15**, 2563). Only methyl chloroform, $CH_3.CCl_3$, related to acetic acid in the same way as chloroform is to formic acid, will be further described, together with the chlorides of the fatty acids. *Acetylene* *tetrachloride*, sym.-*Tetrachlorethane*, $CHCl_2.CHCl_2$ is prepared by the direct union of acetylene and chlorine (p. 87). The gases combine quietly when they are led separately into boiling water, or when sulphur chloride is alternately saturated with chlorine and acetylene in presence of iron powder (C. 1905, I. 1585; 1096, II. 746).

Perchlorethane, C_2Cl_6, m.p. 187°; b.p. $_{776\cdot 7}$ 185·5°, D=2·01, results, together with perchlorobenzene (Z. Electroch. **8,** 165), from the direct union of carbon and chlorine when an electric arc is struck in an atmosphere of chlorine. A good yield is obtained when carbon tetrachloride is warmed with amalgamated aluminium (B. **38,** 3058). It forms a crystalline mass, with a camphor-like odour. It sublimes at the ordinary pressure, as its critical pressure lies below 760 mm. When its vapours are conducted through a tube heated to redness it breaks down into Cl_2 and *perchlorethylene.* It yields the latter compound when it is treated with potassium sulphide.

a-Tribromethane, $CH_3.CBr_3$, has not yet been prepared.

Acetylene Tetrabromide, $CHBr_2.CHBr_2$, is obtained from acetylene and bromine. Zinc dust and alcohol convert it into acetylene dibromide (A. **221,** 141), whilst benzene and $AlCl_3$ change it into *anthracene* (*q.v.* Vol. II.).

Perbromethane, C_2Br_6, is obtained by the addition of bromine to acetylene tetrabromide in the presence of aluminium bromide (C. 1898, I. 882). It is a colourless, crystalline compound, dissolving with difficulty in alcohol and ether. It breaks down at 200° into bromine and *perbromethylene,* $CrBr_4$.

Five structural cases are possible for trisubstituted propane. The most important of these derivatives have the structure $CH_2X.CHX.CHX_2$, corresponding with glycerol, $CH_2(OH).CH(OH).CH_2(OH)$. They will be discussed after the latter.

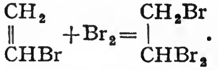
Mixed Halogen Substitution Products of the Paraffins.—There are numerous paraffins containing different halogens side by side in the same molecule.

B. HALOGEN DERIVATIVES OF THE OLEFINES

As a general rule, the halogen substitution products of the unsaturated hydrocarbons cannot be prepared by direct action of the halogens, since addition products are apt to result (p. 82). They are produced, however, by the moderated action of alcoholic potassium hydroxide (C. 1901, I. 816; II. 804), or Ag_2O, on the disubstituted hydrocarbons $C_nH_{2n}X_2$. This reaction occurs very readily if the addition products of the olefines are employed:

$$\underset{\substack{\text{Ethylene}\\\text{Chloride.}}}{C_2H_4Cl_2}+KOH=\underset{\substack{\text{Monochlor-}\\\text{ethylene.}}}{C_2H_3Cl}+KCl+H_2O.$$

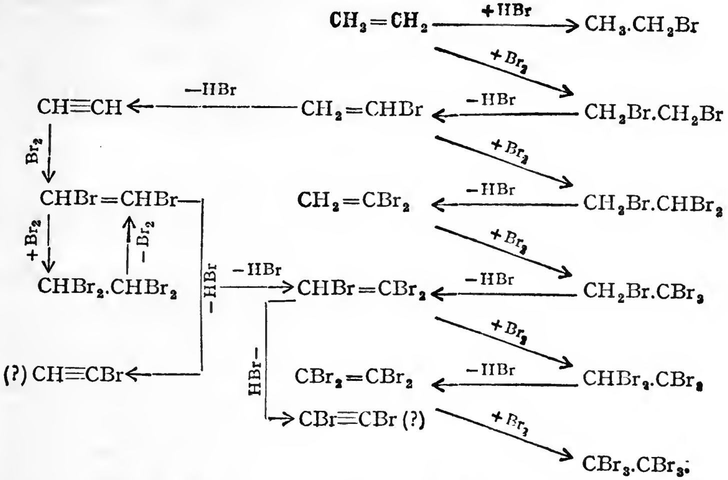
When the alcoholic potassium hydroxide acts very energetically, the hydrocarbons of the acetylene series are formed (p. 86). Being unsaturated compounds they unite directly with the halogens, and also with the halogen acids:



$$\begin{matrix}CH_2\\ \|\\ CHBr\end{matrix}+Br_2=\begin{matrix}CH_2Br\\ |\\ CHBr_2\end{matrix}.$$

These reactions indicate that ethylene is the parent substance for the preparation of nearly all the halogen-substituted ethanes and ethylenes, as well as for the preparation of acetylene.

The following diagram represents how, by the addition of bromine and the loss of hydrogen bromide, the bromine substitution derivatives of the ethanes are connected with ethylene, with the ethylene bromine derivatives, and with acetylene (A. **221**, 156):



Vinyl Chloride, $CH_2=CHCl$, and **Vinyl Bromide,** $CH_2=CHBr$, are obtained from ethylene chloride and ethylene bromide by the action of alcoholic potassium hydroxide, which, by continued action on them, produces acetylene. The group $CH_2=CH-$ is called *vinyl*. Vinyl chloride can also be obtained by heating ethylene dichloride or ethylidene dichloride (B. **35**, 3524).

The boiling points of the *chlorinated* and *brominated ethylenes* are given in the following table:

	Formula.	B.P.	Formula.	B.P.
Vinyl Chloride, Monochlorethylene	$CH_2=CHCl$	−18°	$CH_2=CHBr$	+16°
Acetylene Dichloride, sym.-Dichlorethylene	$CHCl=CHCl$	+55°	$CHBr=CHBr$	110°
Acetylidene Dichloride, unsym.-Dichlorethylene . .	$CH_2=CCl_2$	+37°	$CH_2=CBr_2$	91°
Trichlorethylene	$CHCl=CCl_2$	88°	$CHBr=CBr_2$	164°
Tetrachlorethylene, Perchlorethylene	$CCl_2=CCl_2$	121°	$CBr_2=CBr_2$	M.P. 53°
Tetra-iodoethylene (B. **26**, R. 289; **30**, 1200) .	. . .	. . .	$CI_2=CI_2$	187°

Consult A. **221**, 156, for the relations between the boiling points of the bromethanes and bromethylenes. The unsymmetrical compounds, $CH_2=CHCl$, $CH_2=CHBr$, $CH_2=CCl_2$ and $CH_2=CBr_2$, polymerize quite easily (B **12**, 2076). $CH_2=CBr_2$ and $CHBr = CBr_2$ yield $CH_2Br.COBr$, bromacetyl bromide, and $CHBr_2.COBr$, dibromacetyl bromide (B. **16**, 2918; **21**, 3356) with oxygen. Ozonized air converts perchlorethylene into phosgene, $COCl_2$, and trichloracetyl chloride (B. **27**, R. 509; C. 1899, I. 588). Consult A. **235**, 150, 299, for the action of $AlCl_3$ on polybromethanes and ethylenes, in the presence of benzene.

Tetra-iodoethylene $CI_2:CI_2$ and **Di-iodoethylene** $CHI:CHI$, m.p. 73°, are formed by the action of iodine and water on calcium carbide (B. **38**, 237). **Fluorethylene** (C. 1901, II. 804).

Three different mono-halogen products are derived from **Propylene,** $CH_3-CH=CH_2$:

(1) $CH_3-CH=CHX$	(2) $CH_3-CX=CH_2$	(3) $CH_2X-CH=CH_2$.
α-Derivatives.	β-Derivatives.	γ-Derivatives.

(1) The α-derivatives are obtained from the propylidene compounds,

$CH_3.CH_2.CHX_2$ (from propyl aldehyde), when the latter are heated with alcoholic potassium hydroxide.

(2) The β-derivatives, $CH_3.CX{:}CH_2$, are prepared in pure condition from the halogen compounds, $CH_3.CX_2.CH_3$ (p. 93), derived from acetone.

(3) The γ-derivatives of propylene, $CH_2X-CH=CH_2$, are designated **Allyl halides**, because they correspond with allyl alcohol, $CH_2:CH.CH_2OH$. They will be described after the alkylogens.

C. HALOGEN ACETYLENES

Acetylene Monochloride, C_2HCl, has been obtained from dichloracrylic acid, $CCl_2=CH.CO_2H$, by the action of aqueous barium hydroxide. It is an explosive gas (A. **203**, 88; B. **23**, 3783).

Acetylene Bromide, C_2HBr, obtained from the dibromide by means of alcoholic potassium hydroxide, is a gas, inflaming when in contact with the air.

Dibromacetylene, C_2Br_2, b.p. 77°, $D=2{\cdot}0$, can be prepared from tribromethylene by means of alcoholic potassium hydroxide. It is spontaneously inflammable (C. 1903, II. 531; 1901, I. 231).

Acetylene Di-iodide, C_2I_2, is produced when iodine acts on silver acetylide or calcium carbide, or when iodine and hypochlorites of the alkali metals act on acetylene (B. **37**, 4415); also by boiling barium iodopropiolate with water (A. **308**, 326; B. **34**, 2718). It possesses an odour like phenylisocyanide. It decomposes to a considerable extent into tetra-iodoethylene and carbon in the light or when heated (B. **37**, 3453).

The halogen acetylene derivatives polymerize more easily than acetylene itself. The products are in part benzene derivatives: monobromacetylene yields tribromobenzene.

$$3CH\equiv CBr = \underset{\text{Tribromobenzene.}}{C_6H_3Br_3}; \quad 3CH\equiv CI = \underset{\text{Tri-iodobenzene.}}{C_6H_3I_3}.$$

Allylene Iodide, $CH_3 \vdots CI$, b.p. 110°, is formed from silver allylene and iodine solution (A. **308**, 309).

Perchloromesole, $C_4Cl_6=CCl_3.C\equiv C.CCl_3$ (?) or $CCl_2=CCl-CCl=CCl_2$ (?), m.p. 39°, b.p. 284°, may be mentioned here. It frequently appears in exhaustive chlorinations (B. **10**, 804; comp. B. **22**, 1269)

OXYGEN DERIVATIVES OF THE METHANE HYDROCARBONS

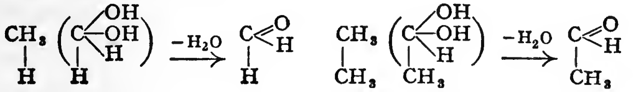
Acquaintance was made with the simplest linkings of the carbon atoms when studying the aliphatic hydrocarbons and their halogen substitution products. The derivatives next in order are the oxygen compounds, which furnish further basis for the classification of the carbon compounds. They may be considered as being derived from the aliphatic hydrocarbons by the substitution of the univalent water residue—the hydroxyl group—OH, for hydrogen.

But one of the several hydroxyl groups may become attached to each carbon atom. In the first instance *alcohols* result, which are neutral compounds, closely related in many respects to water. Alcohols, according to the number of hydroxyl groups present in them, are classified as mono-, di-, tri-, and poly-hydric, because in the alcohols with one hydroxyl a univalent radical, and in those with two hydroxyls a divalent radical, etc., is in union with the water residues. Therefore the simplest monohydric alcohol contains one carbon atom, the simplest dihydric alcohol two carbon atoms, etc., as indicated in the following arrangement:

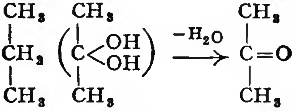
CH_4	$CH_3.OH$	*Methyl Alcohol,* the simplest monohydric alcohol.
$\begin{array}{l}CH_3\\\|\\CH_3\end{array}$	$\begin{array}{l}CH_2.OH\\\|\\CH_2.OH\end{array}$	*Ethylene Glycol,* the simplest dihydric alcohol.
$\begin{array}{l}CH_3\\\|\\CH_2\\\|\\CH_3\end{array}$	$\begin{array}{l}CH_2.OH\\\|\\CH.OH\\\|\\CH_2.OH\end{array}$	*Glycerol,* the simplest trihydric alcohol.
$\begin{array}{l}CH_3\\\|\\CH_2\\\|\\CH_2\\\|\\CH_3\end{array}$	$\begin{array}{l}CH_2.OH\\\|\\CH.OH\\\|\\CH.OH\\\|\\CH_2.OH\end{array}$	*Erythritol,* the simplest tetrahydric alcohol.
$\begin{array}{l}CH_3\\\|\\CH_2\\\|\\CH_2\\\|\\CH_2\\\|\\CH_3\end{array}$	$\begin{array}{l}CH_2.OH\\\|\\CH.OH\\\|\\CH.OH\\\|\\CH.OH\\\|\\CH_2.OH\end{array}$	*Arabitol,* the simplest pentahydric alcohol.
$\begin{array}{l}CH_3\\\|\\CH_2\\\|\\CH_2\\\|\\CH_2\\\|\\CH_2\\\|\\CH_3\end{array}$	$\begin{array}{l}CH_2.OH\\\|\\CH.OH\\\|\\CH.OH\\\|\\CH.OH\\\|\\CH.OH\\\|\\CH_2.OH\end{array}$	*Mannitol,* the simplest hexahydric alcohol.

Or, hydrogen atoms attached to the same carbon atom of hydrocarbons are replaced by —OH groups. In such cases, with few exceptions, water splits off, and oxygen unites with its full valence to carbon. The following possibilities then arise: two hydroxyl groups replace two hydrogen atoms of a terminal CH_3-group, or of an intermediate CH_2-group; three hydroxyl groups replace three hydrogen atoms of a terminal CH_3 group; in either case, water always separates, *e.g.:*

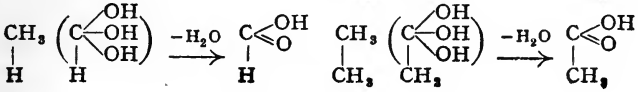
(1)



(2)



(3)



Thus, three new classes of oxygen derivatives are formed:

(1) Compounds containing the group $-C{<}^{O}_{H}$ are known as *Aldehydes,* where the group $-C{<}^{O}_{H}$ is called the aldehyde group.

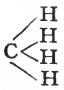
(2) Compounds containing the group $=C=O$ in union with two carbon atoms are called *Ketones.* The group $=CO$ is known as the keto- or ketone group.

(3) Compounds containing the group $-C{<}^{O-H}_{O}$ are named *Carboxylic acids,* in which the group $-C{<}^{O}_{O-H}$ is called *carboxyl.* The alcohols, aldehydes, and ketones are neutral substances. The carboxylic acids are pronounced acids, and form salts in the same manner as the mineral acids.

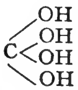
Aldehydes, ketones, and carboxylic acids are most intimately related to the monohydric alcohols. They are the oxidation products of alcohols, and will be discussed after them. Unsaturated hydrocarbons (olefines and acetylenes), in like manner, yield unsaturated alcohols, aldehydes, ketones, and carboxylic acids. In the following sections the unsaturated derivatives will receive attention after the saturated compounds corresponding with them; *i.e.* the unsaturated alcohols will follow the saturated alcohols.

Similarly, an almost endless series of oxidation products are connected with the di-, tri-, and poly-hydric alcohols. These contain the same oxygen-containing atomic groups, as the monohydric alcohols and their oxidation products, but possess several of them in the same molecule. The multiplicity grows rapidly; as will be seen later, nine classes of oxidation products may be derived from the dihydric alcohols or glycols alone.

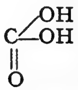
Finally, when in methane, the *four* hydrogen atoms are replaced by hydroxyl groups, the loss of two molecules of water would be possible, and carbon dioxide, the anhydride of two acids incapable of free existence (orthocarbonic acid and ordinary metacarbonic acid) would be obtained. The carbonates are derived from the meta-acid.



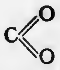
Methane.



Orthocarbonic Acid.



Metacarbonic Acid.



Carbon Dioxide.

The carbonates are salts of a dibasic acid. Therefore, carbonic acid, with its numerous derivatives, will be discussed before the dicarboxylic acids, the final oxidation products of the dihydric alcohols or glycols, whose simplest representative is oxalic acid.

III. THE MONOHYDRIC ALCOHOLS AND THEIR OXIDATION PRODUCTS

1. MONOHYDRIC ALCOHOLS

The monohydric alcohols can be looked upon as consisting of water in which one hydrogen atom has been replaced by a monovalent hydrocarbon residue. If both hydrogen atoms in water are so substituted, there result the ethers, which are at the same time alkyl oxides or alcoholic anhydrides.

$$\left.\begin{matrix}H\\H\end{matrix}\right\}O \qquad \left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O \qquad\qquad \left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O$$

Ethyl Alcohol. Ethyl Ether.

The monohydric alcohols contain one hydroxyl group, OH; bivalent oxygen links the univalent alcohol radical to hydrogen, as in $CH_3.O.H$, methyl alcohol. This hydrogen atom is characterized by its ability, in the action of acids on alcohol, to be exchanged for acid residues, forming compound ethers or *esters*, corresponding with the salts of mineral acids:

$$C_2H_5.OH + NO_2.OH = C_2H_5.O.NO_2 + H_2O$$

Ethyl Alcohol. Ethyl Nitrate or Nitric Ethyl Ester.

Alkyls and metals can also replace the hydrogen in alcohol:

$$C_2H_5.O.CH_3 \qquad C_2H_5.ONa$$

Ethyl Methyl Ether. Sodium Ethoxide.

Structure of the Monohydric Alcohols.—The possible isomeric alcohols may be readily derived from the hydrocarbons. There is one possible structure for the first two members of the normal alcohols:

$$CH_3.OH \qquad C_2H_5.OH$$

Methyl Alcohol. Ethyl Alcohol.

Two isomers can be obtained from propane, $C_3H_8 = CH_3.CH_2.CH_3$:

$$CH_3.CH_2.CH_2.OH \quad \text{and} \quad CH_3.CH(OH).CH_3$$

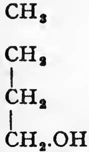
Propyl Alcohol. Isopropyl Alcohol.

Two isomers correspond with the formula C_4H_{10} (p. 27):

$$CH_3.CH_2.CH_2.CH_3 \quad \text{and} \quad CH(CH_3)_3$$

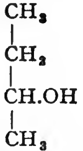
Normal Butane. Isobutane.

Two isomeric alcohols may be obtained from each of these:

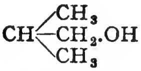


Primary Butyl Alcohol.

and

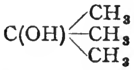


Secondary Butyl Alcohol.



Prim. Isobutyl Alcohol.

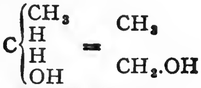
and



Tert. Isobutyl Alcohol.

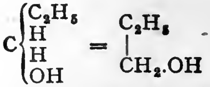
An excellent method of formulating the alcohols was introduced by *Kolbe* in 1860 (A. **113**, 307; **132**, 102). He regarded all alcohols as derivatives of methyl alcohol, for which he proposed the name *carbinol*, and compared the alcohols, formed by the replacement of hydrogen not in union with oxygen by alcohol radicals, with the primary, secondary, and tertiary amines, resulting from the replacement of the hydrogen in ammonia by alcohol radicals. With this view as a basis, *Kolbe* predicted the existence of secondary and tertiary alcohols.

Their first representative was discovered shortly afterwards. By the replacement of one hydrogen atom in carbinol by alkyls (p. 43) the *primary alcohols* result:



$$C\left\{\begin{matrix}CH_3\\H\\H\\OH\end{matrix}\right. = \begin{matrix}CH_3\\ \\CH_2.OH\end{matrix}$$

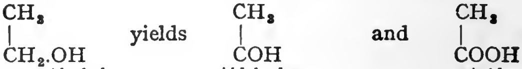
Methyl Carbinol, or Ethyl Alcohol.



$$C\left\{\begin{matrix}C_2H_5\\H\\H\\OH\end{matrix}\right. = \begin{matrix}C_2H_5\\|\\CH_2.OH\end{matrix}$$

Ethyl Carbinol or Propyl Alcohol.

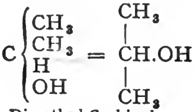
If the replacing group possesses normal structure (p. 27), the primary alcohols are said to be *normal*. In alcohols of this class the carbon atom carrying the hydroxyl group has two additional hydrogen atoms (they contain the group —$CH_2.OH$). Hence compounds of this variety may very easily pass into aldehydes (containing the CHO group) and acids (with COOH group) on oxidation (see p. 100):



$$\begin{matrix}CH_3\\|\\CH_2.OH\end{matrix} \text{ yields } \begin{matrix}CH_3\\|\\COH\end{matrix} \text{ and } \begin{matrix}CH_3\\|\\COOH\end{matrix}$$

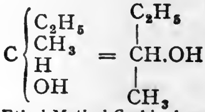
Primary Alcohol. Aldehyde. Acid.

The *secondary alcohols* result when two hydrogen atoms in carbinol, $CH_3.OH$, are replaced by alkyls:



$$C\left\{\begin{matrix}CH_3\\CH_3\\H\\OH\end{matrix}\right. = \begin{matrix}CH_3\\|\\CH.OH\\|\\CH_3\end{matrix}$$

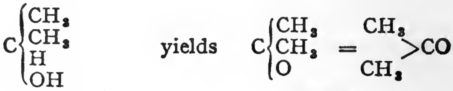
Dimethyl Carbinol, or Isopropyl Alcohol.



$$C\left\{\begin{matrix}C_2H_5\\CH_3\\H\\OH\end{matrix}\right. = \begin{matrix}C_2H_5\\|\\CH.OH\\|\\CH_3\end{matrix}$$

Ethyl Methyl Carbinol, or Isobutyl Alcohol.

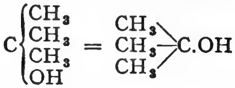
In alcohols of this class the carbon atom carrying the OH group has but one additional hydrogen atom; they contain the group $>CH.OH$. They do not furnish corresponding aldehydes and acids, but when oxidized, they pass into ketones (p. 100):



$$C\left\{\begin{matrix}CH_3\\CH_3\\H\\OH\end{matrix}\right. \text{ yields } C\left\{\begin{matrix}CH_3\\CH_3\\O\end{matrix}\right. = \begin{matrix}CH_3\\ \\CH_3\end{matrix}\!\!>CO$$

Dimethyl Carbinol. Acetone.

When, finally, all three hydrogen atoms in carbinol are replaced by alkyls, there result the *tertiary alcohols*, containing the group $/C.OH$.



$$C\left\{\begin{matrix}CH_3\\CH_3\\CH_3\\OH\end{matrix}\right. = \begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\!\!>C.OH$$

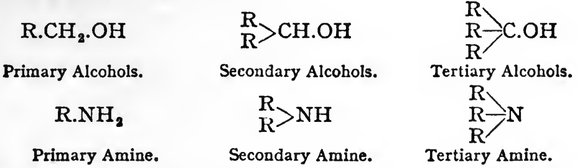
Trimethyl Carbinol.

The tertiary alcohols decompose when oxidized.

The "Geneva names" for the alcohols are derived from the names of the corresponding hydrocarbons, with the addition of the final syllable "ol":

$CH_3.OH$=[Methanol]; $CH_3.CH_2.OH$=[Ethanol]:
$CH_3.CH_2.CH_2.OH$=[1-Propanol]; $CH_3.CHOH.CH_3$=[2-Propanol].

The parallelism between the formulæ of the three classes of alcohols and the three classes of amines (*q.v.*), is very evident upon studying the following general formulæ :—



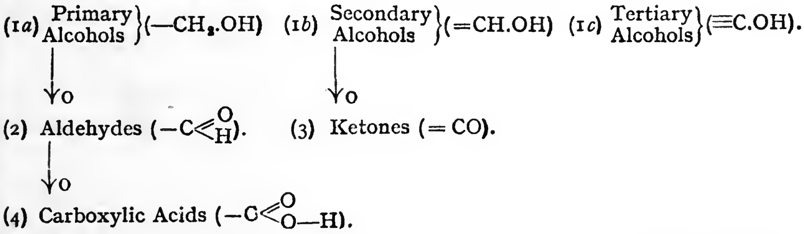
$R.CH_2.OH$	$\begin{matrix}R\\R\end{matrix}>CH.OH$	$\begin{matrix}R\\R\\R\end{matrix}\Big\rangle C.OH$
Primary Alcohols.	Secondary Alcohols.	Tertiary Alcohols.
$R.NH_2$	$\begin{matrix}R\\R\end{matrix}>NH$	$\begin{matrix}R\\R\\R\end{matrix}\Big\rangle N$
Primary Amine.	Secondary Amine.	Tertiary Amine.

The behaviour of alcohols on oxidation is of great importance in ascertaining whether a certain alcohol is primary, secondary, or tertiary in character. What has already been stated may be summarized thus :

A *primary* alcohol on oxidation yields an *aldehyde*, which passes into a carboxylic acid if the action be continued. This acid contains as many carbon atoms in its molecule as the parent alcohol. Oxidation changes a secondary alcohol into a *ketone*, having an equal number of carbon atoms in its molecule. A *tertiary* alcohol breaks down on oxidation into compounds having a lower carbon content.

The basis of the classification of the next section is :

The monohydric alcohols and their oxidation products :



(1*a*) Primary Alcohols ($-CH_2.OH$) (1*b*) Secondary Alcohols ($=CH.OH$) (1*c*) Tertiary Alcohols ($\equiv C.OH$).

(2) Aldehydes ($-C\begin{smallmatrix}O\\H\end{smallmatrix}$). (3) Ketones ($=CO$).

(4) Carboxylic Acids ($-C\begin{smallmatrix}O\\O-H\end{smallmatrix}$).

Four classes of oxygen derivatives must, therefore, be distinguished, each containing saturated and unsaturated compounds.

Formation of Alcohols.—*Summary of Reactions.*—They are obtained from bodies containing a like number of carbon atoms :

(1) By the saponification of acid esters.

(2) By the reduction of polyhydric alcohols.

(3) By the action of nitrous acid on amines.

(4) By the reduction of their oxidation products.

From nucleus-syntheses (p. 75) :

(5) By the action of magnesium alkyl halide or zinc alkyls, or zinc and alkyl iodides, on aldehydes, acid chlorides, ketones, formic esters, acetic esters, chlorinated ethers and ethylene oxide.

(1*a*) *From Haloid Esters or Alkylogens.*—It was mentioned, in describing the reactions of the alkylogens, that the latter afford a means of passing from the paraffins and olefines to the alcohols (p. 93). As alkali hydroxide causes the separation of a halogen acid from the alkylogens, it is possible to exchange hydroxyl for the halogen, especially if this be iodine. This is most easily accomplished by the action of freshly precipitated, moist silver oxide, or by heating with lead oxide and water :

$$C_2H_5I + AgOH = C_2H_5.OH + AgI.$$

Thus, moist silver oxide behaves as a metallic hydroxide.

Even water alone causes a partial transposition of the more reactive tertiary alkyl iodides; the other alkylogens in general when heated for some time with 10–15 volumes of water to 100° are completely converted into alcohols (A. **186**, 390).

Tertiary alkyl iodides heated to 100° with methyl alcohol pass into alcohols and methyl iodide (A. **220**, 158).

(1*b*) *By the Saponification of their Esters.*—It is often more practical first to convert the halogen derivatives into acetic acid esters, by heating with silver or potassium acetate:

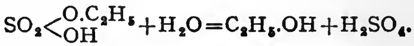
$$\underset{}{C_2H_5Br} + \underset{\text{Potassium Acetate.}}{C_2H_3O.OK} = \underset{\text{Ethyl Acetic Ester.}}{C_2H_5.O.C_2H_3O} + KBr$$

and then to boil these with potassium or sodium hydroxide, to obtain the alcohols:

$$C_2H_5.O.C_2H_3O + KOH = C_2H_5.OH + C_2H_3O.OK.$$

The second reaction is called *saponification*, because by means of it the soaps, *i.e.* the alkali salts of the fatty acids and glycerol (*q.v.*), are obtained from the glycerol esters of the fatty acids—the fats. More generally, this reaction is known as *hydrolysis*: both terms are, unfortunately, employed somewhat loosely (Tr.).

(1*c*) *From Ethyl Sulphuric Acid by boiling water.*



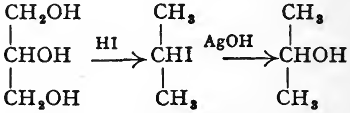
$$SO_2{<}^{O.C_2H_5}_{OH} + H_2O = C_2H_5.OH + H_2SO_4.$$

Ethyl Sulphuric Acid.

This reaction constitutes the transition from the olefines to the alcohols, as these esters may be easily obtained by directly combining the unsaturated hydrocarbons with sulphuric acid.

Many alkylenes (like iso- and pseudo-butylene) dissolve at once in dilute nitric acid, absorb water, and yield alcohols (A. **180**, 245).

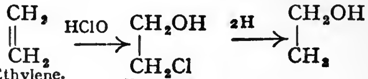
(2) *The reduction of polyhydric alcohols* by hydriodic acid yields the iodides of secondary alcohols, which are converted by methods 1*a* and 1*b* into the alcohols themselves, *e.g.*:



$$\begin{matrix} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{matrix} \xrightarrow{HI} \begin{matrix} CH_3 \\ | \\ CHI \\ | \\ CH_3 \end{matrix} \xrightarrow{AgOH} \begin{matrix} CH_3 \\ | \\ CHOH \\ | \\ CH_3 \end{matrix}$$

Glycerol. Isopropyl Iodide. Isopropyl Alcohol.

Or, the chlorhydrins of the polyhydric alcohols may be reduced, *e.g.*:



$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} \xrightarrow{HClO} \begin{matrix} CH_2OH \\ | \\ CH_2Cl \end{matrix} \xrightarrow{2H} \begin{matrix} CH_2OH \\ | \\ CH_3 \end{matrix}$$

Ethylene. Ethylene Chlorhydrin.

(3) *Action of nitrous acid on the primary amines:*

$$C_2H_5NH_2 + NO.OH = C_2H_5.OH + N_2 + H_2O.$$

In the case of the higher alkylamines transpositions often occur, and instead of the primary alcohols, there result secondary alcohols (B. **16**, 744).

(4*a*) Primary alcohols result from the reduction of *aldehydes, acid chlorides*, and *acid anhydrides*; also, by reduction of *acid esters* by means of sodium and alcohol; *acid amides* yield primary amines as well as primary alcohols by this reaction (C. 1904, I. 577; II. 1697).

$C_2H_5.HCO + 2H = CH_3.CH_2.CH_2.OH$ (*Würtz*, A. **123**, 140).
Propyl Aldehyde.

$CH_3.COCl + 4H = CH_3.CH_2.OH + HCl.$
Acetyl Chloride.

$\left.\begin{matrix}CH_3.CO\\CH_3.CO\end{matrix}\right>O + 4H = C_2H_5.OH + CH_3.COOH$ (*Linnemann*, A. **148**, 249).
Acetic Anhydride.

$\left.\begin{matrix}CH_3CO\\C_5H_{11}\end{matrix}\right>O + 4Na + 2C_5H_{11}OH = CH_3.CH_2.ONa + 3C_5H_{11}ONa$ * (*Bouveault* and
Amyl Acetic Ester.

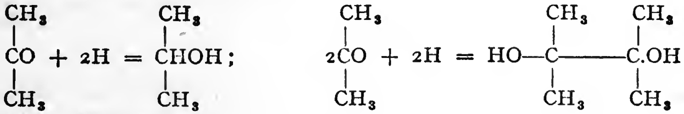
Blanc, C. 1904, II. 184; 1905, II. 1700).

Aldehydes are first formed in the reduction of acid chlorides and anhydrides; they in turn are reduced to alcohols. As reducing agents, dilute sulphuric acid or acetic acid, together with sodium amalgam, sodium, iron filings, and zinc dust may be employed (B. **9**, 1312; **16**, 1715).

The last of these reactions is that by which an alcohol can be converted into another containing an atom more of carbon. The alcohol is changed through the iodide to the cyanide, and the latter to the acid, which, by reduction of its chloride or its aldehyde, yields the new alcohol:

$$CH_3OH \longrightarrow CH_3I \longrightarrow CH_3CN \longrightarrow CH_3COOH \longrightarrow CH_3COCl \longrightarrow CH_3CH_2OH$$

(4*b*) *The reduction of ketones* yields *secondary alcohols* (*Friedel*, A. **124**, 324), together with pinacones (*q.v.*), the di-tertiary dihydric alcohols or glycols:



$$\begin{matrix}CH_3\\|\\CO\\|\\CH_3\end{matrix} + 2H = \begin{matrix}CH_3\\|\\CHOH\\|\\CH_3\end{matrix}; \quad 2\begin{matrix}CH_3\\|\\CO\\|\\CH_3\end{matrix} + 2H = HO-\begin{matrix}CH_3\\|\\C\\|\\CH_3\end{matrix}-\begin{matrix}CH_3\\|\\C.OH\\|\\CH_3\end{matrix}$$

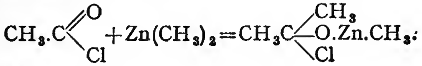
Acetone. Isopropyl Alcohol. Pinacone.

Nucleus-synthetic Methods of Formation.

(5*a*) *Acid Chlorides and Zinc Alkyls; Ketones, Zinc Alkyls and Alkylogens.*—A very remarkable synthetic method, proposed by *Butlerow* (1864), which led to the discovery of the **tertiary** alcohols, consists in the action of the zinc compounds of the alkyls on the chlorides of the acid radicals (Z. Ch., 1864, 385; 1865, 614).

The reaction proceeds in three stages. At first only one molecule of zinc alkyl reacts, and forms an addition compound with the acid chloride, as a result of the breaking down of the double linkage between the carbon and oxygen:

I.

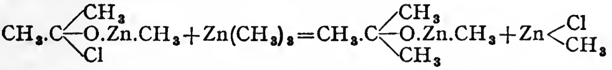


$$CH_3.C\begin{matrix}\diagup O\\ \diagdown Cl\end{matrix} + Zn(CH_3)_2 = CH_3C\begin{matrix}\diagup CH_3\\ -O.Zn.CH_3\\ \diagdown Cl\end{matrix}.$$

Acetyl Chloride.

By decomposing the reaction-product with water, acetone is formed. However, should a second molecule of the zinc alkyl act upon the new compound, further reaction will take place on longer standing:

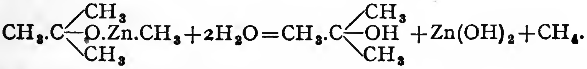
II.



$$CH_3.C\begin{matrix}\diagup CH_3\\ -O.Zn.CH_3\\ \diagdown Cl\end{matrix} + Zn(CH_3)_2 = CH_3.C\begin{matrix}\diagup CH_3\\ -O.Zn.CH_3\\ \diagdown CH_3\end{matrix} + Zn\begin{matrix}\diagup Cl\\ \diagdown CH_3\end{matrix}$$

If water be now permitted to react, a tertiary alcohol will be formed:

III.



$$CH_3.C\begin{matrix}\diagup CH_3\\ -O.Zn.CH_3\\ \diagdown CH_3\end{matrix} + 2H_2O = CH_3.C\begin{matrix}\diagup CH_3\\ -OH\\ \diagdown CH_3\end{matrix} + Zn(OH)_2 + CH_4.$$

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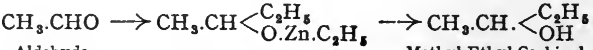
* Altered from German edition, according to original paper, Bull. soc. chim. [3] **31**, 672 (Tr.).

If, in the second stage, the zinc compound of another radical be employed, the latter may be introduced, and in this manner we obtain tertiary alcohols containing two or three different alkyl groups (A. **175**, 374, and **188**, 110, 122; C. 1910, II. 1201).

It is remarkable that only zinc methyl and zinc ethyl furnish tertiary alcohols, whilst zinc propyl produces only those of the secondary type (B. **16**, 2284; **24**, R. 667).

The *ketones* in general do not react with the zinc alkyls. On the other hand, there are ketones which do not contain a CH_3 group united to a CO group, such as diethyl ketone $(C_2H_5)_2CO$, dipropyl ketone $(C_3H_7)_2CO$, and ethyl propyl ketone $C_2H_5.CO.C_3H_7$, which are converted by zinc and methyl or ethyl iodide into zinc alkyl compounds; these, under the influence of water, pass into *tertiary* alcohols (B. **19**, 60; **21**, R. 55). Unsaturated tertiary alcohols are obtained from all the ketones by the action of zinc and allyl iodide (A. **196**, 113).

(5*b*) When zinc alkyls act upon aldehydes, only one alkyl group enters the molecule, and the reaction-product of the first stage yields a *secondary* alcohol when treated with water (A. **213**, 369; and B. **14**, 2557):

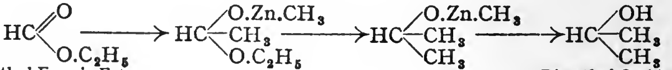


$$CH_3.CHO \longrightarrow CH_3.CH\!<\!\begin{smallmatrix}C_2H_5\\O.Zn.C_2H_5\end{smallmatrix} \longrightarrow CH_3.CH.\!<\!\begin{smallmatrix}C_2H_5\\OH\end{smallmatrix}$$

Aldehyde. Methyl Ethyl Carbinol.

All aldehydes (even those with unsaturated alkyls, and also furfural) react in this way—but only with zinc methyl and zinc ethyl, whilst with the higher zinc alkyls the aldehydes undergo reduction to their corresponding alcohols (B. **17**, R. 318). With zinc methyl, chloral, $CCl_2.CHO$, yields trichlorisopropyl alcohol, $CCl_3.CH(OH).CH_3$; whereas with zinc ethyl it is only reduced to trichlorethyl alcohol (A. **223**, 162).

(5*c*) Just as tertiary alcohols are obtained from the acid radicals, so *secondary alcohols* are derived from the esters of formic acid. Zinc alkyls (or, better, alkyl iodides and zinc), are allowed to react in this case, and two alkyls are introduced:



$$HC\!<\!\begin{smallmatrix}O\\O.C_2H_5\end{smallmatrix} \longrightarrow HC\!\begin{smallmatrix}O.Zn.CH_3\\CH_3\\O.C_2H_5\end{smallmatrix} \longrightarrow HC\!\begin{smallmatrix}O.Zn.CH_3\\CH_3\\CH_3\end{smallmatrix} \longrightarrow HC\!\begin{smallmatrix}OH\\CH_3\\CH_3\end{smallmatrix}$$

Ethyl Formic Ester. Dimethyl Carbinol.

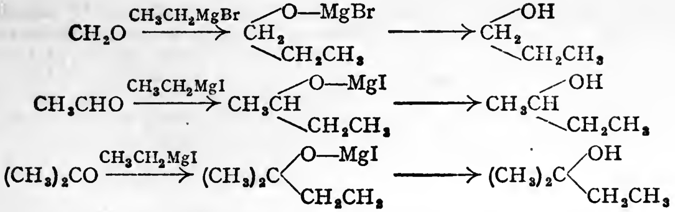
By using some other zinc alkyl in the second stage of the reaction, or by working with a mixture of two alkyl iodides and zinc, two different alkyls may also be introduced here (A. **175**, 362, 374).

Zinc and allyl iodide (not ethyl iodide, however) react similarly with acetic acid esters. Two alkyl groups are introduced and unsaturated tertiary alcohols formed (A. **185**, 175).

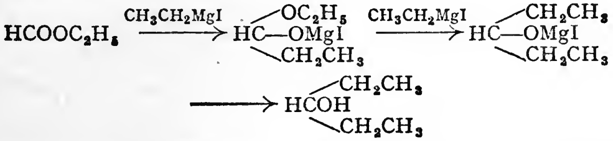
Chlorinated ethers, *e.g.* $ClCH_2.OCH_3$, and zinc alkyls yield ethers of primary alcohols (B. **24**, R. 858):

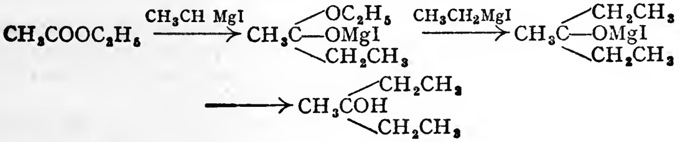
$$2Cl.CH_2.OCH_3+Zn(C_2H_5)_2=2C_2H_5.CH_2.OCH_3+ZnCl_2.$$

(6) Alkyl magnesium halides react similarly to the zinc alkyls with aldehydes and ketones. They are soluble in ether, are more convenient to deal with and are generally more valuable. The alkyl magnesium halides unite with aldehydes and ketones by breaking the double oxygen bond, and subsequently give up the particular alcohol on the addition of acidified water to the addition compound. Polymerized formaldehyde (trioxymethylene) gives rise to a primary alcohol, the other aldehydes to secondary and the ketones to tertiary alcohols (*Grignard*):



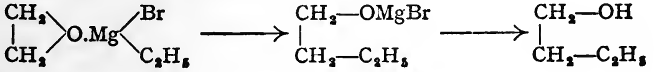
By similar reactions formic acid esters yield secondary alcohols, whilst alkyl carboxylic acid esters and carboxylic acid chlorides and anhydrides give rise to tertiary alcohols:



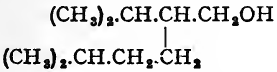


In many reactions the tertiary alcohols which are first formed lose water and so become converted into unsaturated hydrocarbons, which may thus constitute the secondary or even the main product of the reaction (C. 1901, I. 725; II. 622; 1902, I. 414).

Primary alcohols are also obtained by warming the addition-products of ethylene oxide with the alkyl magnesium halides (C. 1903, II. 105; 1907, I. 1102):



(7) The action of sodium or barium alcoholates on alcohols of the same name—especially among those of high molecular weight—leads to the formation of monohydric alcohols possessing two or three times the carbon content in the molecule (B. 34, 3246; C. 1902, I. 743). For instance: amyl alcohol gives rise to a decyl alcohol of the constitution isopropyl isoamyl ethyl alcohol.

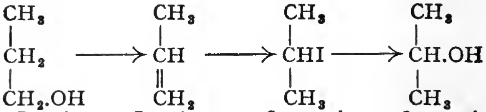


$$\begin{array}{l}\qquad\quad (CH_3)_2.CH.CH.CH_2OH \\ \qquad\qquad\qquad\qquad\;\; | \\ (CH_3)_2.CH.CH_2.CH_2\end{array}$$

(A. 318, 157).

In addition to the above universal methods, alcohols are formed by various other reactions. Their formation in the alcoholic fermentation of sugars in the presence of ferments is of great practical importance. Appreciable quantities of methyl alcohol are produced in the dry distillation of wood. Many alcohols, too, exist in combination as already formed natural products in compounds, chiefly as compound esters of organic acids.

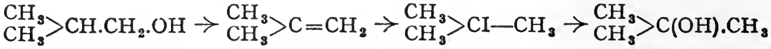
Conversion of Primary into Secondary and Tertiary Alcohols.—By the elimination of water the primary alcohols become unsaturated hydrocarbons C_nH_{2n} (p. 82). The latter, treated with concentrated HI, yield iodides of secondary alcoholic radicals, as iodine does not attach itself to the terminal but to the less hydrogenized carbon atom (p. 84). Secondary alcohols result when these iodides are acted on with silver oxide. The successive conversion is illustrated in the following formulæ:



$$\begin{matrix} CH_3 & & CH_3 & & CH_3 & & CH_3 \\ | & & | & & | & & | \\ CH_2 & \longrightarrow & CH & \longrightarrow & CHI & \longrightarrow & CH.OH \\ | & & \| & & | & & | \\ CH_2.OH & & CH_2 & & CH_3 & & CH_3 \end{matrix}$$

Propyl Alcohol. Propylene. Isopropyl Iodide. Isopropyl Alcohol.

In a similar manner primary alcohols in which the group $CH_2.OH$ is joined to a secondary radical, pass into tertiary alcohols:



$$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CH.CH_2.OH \rightarrow \begin{matrix}CH_3\\CH_3\end{matrix}\!>C{=}CH_2 \rightarrow \begin{matrix}CH_3\\CH_3\end{matrix}\!>CI{-}CH_3 \rightarrow \begin{matrix}CH_3\\CH_3\end{matrix}\!>C(OH).CH_3$$

Isobutyl Alcohol. Isobutylene. Tertiary Butyl Iodide. Tertiary Butyl Alcohol.

The change is better effected by the aid of sulphuric acid. The sulphuric esters (p. 84), arising from the alkylenes, C_nH_{2n}, have the sulphuric acid residue linked to the carbon atom with the least number of attached hydrogen atoms.

Physical Properties.—In physical properties alcohols exhibit a gradation corresponding with their increase in molecular weight like other bodies belonging to homologous series. The lower alcohols are mobile liquids, dissolving readily in water, and possessing the characteristic alcoholic odour and burning taste. As their carbon content increases, their solubility in water grows rapidly less. The normal alcohols, containing from one to sixteen carbon atoms, are fluid at the ordinary temperature, whilst the higher members are crystalline solids, without odour or taste, resembling the fats. Their boiling points increase gradually (with similar structure) in proportion to the increase of their molecular weights, the rise being about 20° for a difference of CH_2. The primary alcohols boil higher than the isomeric secondary, and the latter higher than the tertiary alcohols. Here we observe again that the boiling points are lowered by an accumulation of methyl groups (see p. 50).

The boiling points can be calculated with approximate accuracy from the alkyl residues present (B. **20,** 1948). The higher members are only volatile without decomposition under diminished pressure.

Chemical Properties and Reactions.—The alcohols are neutral compounds. In many respects the first members of the series resemble water, and enter into combination with many salts, in which they behave as *alcohol of crystallization* (p. 110).

Some of the more important reactions are—

(1) The hydroxyl hydrogen is easily replaced by sodium, potassium, and other metals, yielding thereby the *alcoholates or alkoxides* (p. 116).

(2) In their interaction with strong acids water separates and *compound ethers* or *esters* are produced. This reaction, in which the alcohols figure as the base, is analogous to that taking place in the formation of a salt from a basic hydroxide and an acid (p. 116).

(3) The *haloid esters* of the alcohols are produced when the alcohols are heated together with the halogen acids. These esters are the mono-halogen derivatives of the paraffins (p. 93). A more convenient method for their formation consists in heating the alcohols with the phosphorus halides (p. 93).

Nascent hydrogen, acting on these esters, affords a means of reconverting the alcohols into their corresponding hydrocarbons (p. 93).

(4) The primary saturated alcohols, on being passed over finely divided metals (Cu, Ni, Zn, Al) heated to redness, are decomposed into aldehydes. Similarly, secondary alcohols give rise to ketones, and tertiary alcohols to olefines (C. 1903, I. 1212; J. pr. Ch. [2] **67**, 420).

(5) Energetic dehydrating agents convert the alcohols, especially those of the tertiary class, into olefines (p. 82).

Reactions distinguishing Primary, Secondary, and Tertiary Alcohols.—(1) In the preliminary description of the alcohols it was clearly shown that primary alcohols, upon oxidation, yield aldehydes and carboxylic acids; that the secondary alcohols form ketones with like carbon-content (p. 102), and that the tertiary alcohols break down.

(2) If the alcohols be converted by phosphorus iodide (p. 93) into their iodides, and the latter are changed by silver nitrite to nitroalkyls (p. 141), these will show characteristic colour reactions, according as they contain a primary, secondary, or tertiary alcohol radical.

(3) Acetic esters are formed when the primary and secondary alcohols are heated with acetic acid to 155° C. The tertiary alcohols, under similar treatment, lose water and form alkylenes (A. **190**, 343; **197**, 193; **220**, 165)

(4) When the primary alcohols are heated with soda-lime they yield their corresponding acids:

$$R.CH_2.OH+NaOH=R.CO.ONa+2H_2.$$

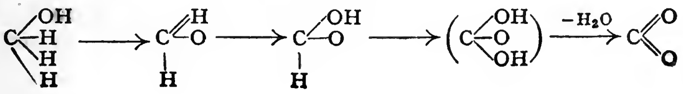
(5) PCl_3 reacts with the primary alcohols to form mainly esters of the type $RO.PCl_2$; with secondary alcohols it produces unsaturated hydrocarbons, and with tertiary alcohols the corresponding alkyl chlorides (C. 1897, II. 334).

(6) Primary and secondary alcohols yield the corresponding acetic acid esters with acetyl chloride CH_3COCl; the tertiary alcohols, on the contrary, give rise to tertiary alkyl halides (C. 1906, II. 747).

A. SATURATED ALCOHOLS, PARAFFIN ALCOHOLS, $C_nH_{2n+1}OH$

The most important members of this series, and of the monohydric alcohols in particular, are *methyl alcohol* or *wood spirit*, $CH_3.OH$, and *ethyl alcohol* or *spirits of wine*: $CH_3.CH_2.OH$.

1. **Methyl Alcohol**, *Wood Spirit, Carbinol* [*Methanol*], $CH_3.OH$, b.p.$_{760}$ 66–67°, $D_{20}=0{\cdot}796$, differs from all other primary alcohols in that it contains the CH_2OH group in union with hydrogen. Hence its oxidation is not restricted to the corresponding monobasic carboxylic acid, but may extend to carbonic acid:



It is formed in large amounts in the dry distillation of wood. The name methyl is derived from μέθυ (wine), and ὕλη (wood).

Physical Properties.—Methyl alcohol is a mobile liquid with spirituous odour and burning taste. It mixes with water, alcohol, and ether.

History.—*Boyle* discovered wood spirit in 1661 among the products of the dry distillation of wood. In 1812 *Taylor* recognized it as being similar to spirits of wine, but considered it an entirely different body. *Dumas* and *Péligot* (1831) (A. **15**, 1) made the first study of it.

Methyl alcohol is also produced in the dry distillation of molasses. It occurs in nature as methyl salicylic ester, $C_6H_4\begin{cases}[1]COOCH_3\\ [2]OH\end{cases}$, *winter-green oil*, derived from *Gaultheria procumbens;* as the methyl ester of anthranilic acid in *neroli oil*, in many alkaloids and other compounds.

The full synthesis of methyl alcohol proceeds from carbon disulphide through methane and methyl chloride, by the action of aqueous potassium hydroxide on the latter at 100° (*Berthelot*, 1858, A. chim. phys. [3] **52**, 101):

$$CS_2 \longrightarrow CH_4 \longrightarrow CH_3Cl \xrightarrow{KOH} CH_3.OH.$$

The aqueous product obtained in the distillation of wood at 500° in iron retorts contains methyl alcohol, acetone, acetic acid, methyl acetic ester, and other compounds. It is distilled over quick-lime or soda, whereby the acetic acid is held back in the form of a salt. Further purification is effected by means of anhydrous calcium chloride, which combines with the alcohol to a crystalline compound. This is removed, freed from acetone by filtration and drying, and afterwards decomposed by distilling with water. Pure aqueous methyl alcohol passes over, which is then dehydrated with lime or anhydrous potassium carbonate. To procure it perfectly pure it is necessary to decompose *oxalic methyl ester*, a readily crystallizable substance, the high-boiling *methyl benzoate*, or *methyl formic ester*, with potassium hydroxide.

To detect ethyl alcohol in methyl alcohol, the liquid is heated with concentrated sulphuric acid, when ethylene is formed from the ethyl alcohol, whilst methyl ether results from the methyl alcohol. The amount of methyl alcohol in wood spirit is determined, quantitatively, by converting it into methyl iodide, CH_3I, through the agency of PI_3 (B. **9**, 1928); the quantity of acetone is estimated by the iodoform reaction (B. **13**, 1000).

Uses.—Wood spirit is employed as a source of heat, and as a denaturizing agent for ethyl alcohol. It is also used in making varnishes, dimethyl aniline, and for the methylation of many carbon derivatives, particularly the dye-stuffs. It is a good solvent for many compounds of carbon.

Chemical Properties.—(1) Methyl alcohol combines directly with $CaCl_2$, to form $CaCl_2.4CH_4O$, crystallizing in brilliant six-sided plates; homologous alcohols give similar compounds (C. 1906, II. 1715). Barium oxide dissolves in methyl alcohol, forming the crystalline body $BaO.2CH_4O$. The alcohol in this salt behaves as *alcohol of crystallization*.

(2) Potassium and sodium dissolve in the anhydrous alcohol, to form methylates, *e.g.* CH_3OK and CH_3ONa.

(3) Oxidizing agents, *e.g.* air in presence of platinum black or copper oxide, change methyl alcohol to formaldehyde, formic acid, and carbon dioxide.

(4) Chlorine and bromine do not act so readily on methyl as

on ethyl alcohol. Chlorine attacks aqueous methyl alcohol, however, quite easily (B. **28**, R. 771). Dichloromethyl ether, $(ClCH_2)_2O$, is first produced which water converts into formaldehyde and hydrochloric acid (B. **26**, 268).

(5) When methyl alcohol is heated with soda-lime, sodium formate results with evolution of hydrogen:

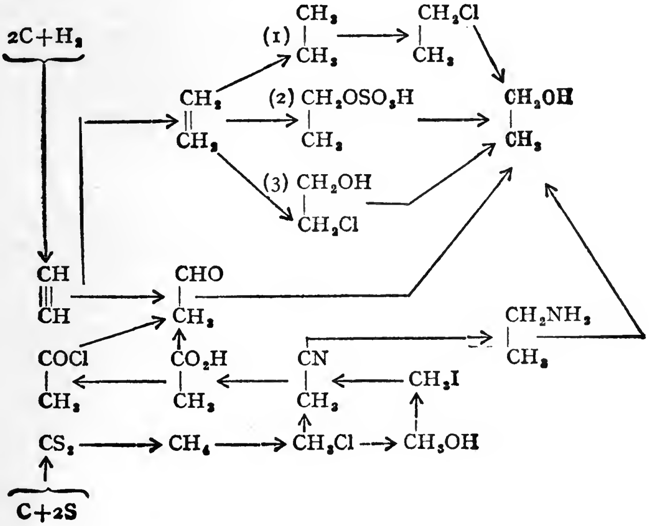
$$CH_3.OH + NaOH = CHO.ONa + 2H_2.$$

(6) When the alcohol is distilled over zinc dust, it breaks down into carbon monoxide and water.

2. **Ethyl Alcohol,** *Spirits of Wine* [*Ethanol*], CH_3CH_2OH, m.p. −112° (B. **33**, 638) b.p.$_{760}$ 78·3°, D_0=0·806, D_{20} 0·789.—In consequence of its formation in the spirituous fermentation of saccharine plant juices, alcohol, in impure state, was known to the ancients. It was, however, only at the end of the eighteenth century that the knowledge of how it might be obtained in an anhydrous condition was first acquired. In 1808 *Saussure* determined its constitution.

Occurrence.—Ethyl alcohol seldom occurs in the vegetable kingdom. It is found, together with ethyl butyrate, in the unripe seeds of *Heracleum giganteum* and *Heracleum spondylium.* It is also present in the urine of diabetic patients. It appears in that of healthy men after excessive consumption of alcoholic beverages.

Formation.—It may be obtained by the general methods previously described for primary alcohols: (1) From ethyl chloride; (2) from ethyl sulphate; (3) from ethylene chlorhydrin; (4) from ethylamine; (5) from aldehyde; and (6) from acetyl chloride or acetic esters. The synthesis of ethyl alcohol is, therefore, possible in two ways. The first three methods show that it is genetically connected with acetylene, ethylene, and ethane, whilst the last three methods indicate its relation to acetylene just as acetic acid and its nitrile are genetically connected with methyl alcohol. These relations are made clear in the following diagram:—



Starting with acetylene, the most direct course to ethyl alcohol would be through acetaldehyde. Water converts it into the latter (p. 87), and nascent hydrogen then reduces the aldehyde to alcohol.

If the acetylene be changed to ethylene, then various possibilities arise for the formation of ethyl alcohol: (1) Ethylene and hydrogen unite to form ethane, which chlorine changes to ethyl chloride, yielding alcohol when heated with water. (2) At 160° ethylene unites with sulphuric acid, forming ethyl sulphuric acid, which boiling water changes to ethyl alcohol and sulphuric acid. In this manner *Berthelot* first carried out the synthesis of ethyl acohol (C. 1899, I. 1018). (3) Ethylene and hypochlorous acid yield ethylene chlorhydrin or monochlorethyl alcohol which may be reduced to ethyl alcohol.

A nucleus-synthesis of ethyl alcohol from methyl alcohol is possible through acetaldehyde. Methyl alcohol can be synthesized from carbon disulphide (p. 110). Phosphorus iodide converts the methyl alcohol into methyl iodide, and this, by action of potassium cyanide, is changed into methyl cyanide. Boiling alkali transforms the latter into an alkali acetate, which phosphorus oxychloride converts into acetyl chloride. The latter, by reduction, yields ethyl alcohol, with acetaldehyde as an intermediate product. Acetaldehyde may also be prepared from calcium acetate by heating it with calcium formate.

Preparation.—Ethyl alcohol is prepared on a technical scale almost exclusively by what is termed the "alcoholic fermentation" of saccharine liquids.

Schwaan, in 1836, and independently *Cagniard Latour*, found that alcoholic fermentation was brought about by yeast cells. This discovery, as opposed to *Liebig's* mechanical fermentation theory (A. **29**, 100; **30**, 250, 363), only found general acceptance from 1857 onwards, through *Pasteur's* investigations (A. chim. phys. [3] **58**, 323). In 1897 *Buchner* showed that the expressed liquid from mechanically broken up yeast cells could also bring about alcoholic fermentation. It is not yet settled whether the capacity for causing fermentation is due to the presence of an enzyme-like body, *zymase* (enzyme theory), or whether it results from the action of living protoplasm (plasma hypothesis (B. **32**, 2086, 2372; **33**, 971, 2764, with bibliography; C. 1900, I. 1033; 1091, II. 700).

By "spirituous" or "alcoholic" fermentation is understood the breaking down of certain kinds of sugar into alcohol and carbon dioxide by yeast, an *organized* ferment, which consists of microscopic cells, about 0·01 mm. in diameter, and is known as *saccharomyces cerevisiae seu vini*.

Conditions of Alcoholic Fermentation.—The yeast germs increase by budding in dilute, warm (5–30°) sugar solutions: the growth is most rapid at 20–30° C. Its development requires salts, especially phosphates, and albuminous substances, as well as oxygen at the commencement (B. **29**, 1983), but the fermentation proceeds afterwards without access of air. When the quantity of alcohol in a fermenting liquid reaches a certain amount, the fermentation ceases, since the yeast germs cannot grow in liquids containing 14 per cent. of alcohol. They are also destroyed by a temperature of 60°, and by small quantities of phenol, salicylic acid, mercuric chloride, and other disinfectants.

The sugars occurring in ripening fruits—grapes, apples, cherries—and in cane and beet, as well as in many other plants, belong to the class of *carbohydrates*, which contain carbon, together with hydrogen and oxygen in the same proportion in which they are present in water. The carbohydrates will be discussed immediately after the hexahydric alcohols: $C_6H_8(OH)_6$—*mannitol*, *dulcitol*, *sorbitol*, etc., of which the first oxidation products are the simple carbohydrates, $C_6H_{12}O_6$. However, so much relating to the carbohydrates will be given at this time as appears necessary to understand alcoholic fermentation.

The carbohydrates may be arranged in three principal classes:

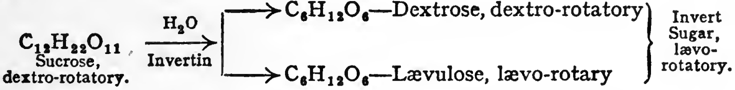
1. *Glucoses* or *Monoses*, $C_6H_{12}O_6$: dextrose, lævulose, etc.
2. *Saccharobioses*, $C_{12}H_{22}O_{11}$: maltose, sucrose, lactose, etc.
3. *Polysaccharides* $(C_6H_{10}O_5)_x$: starch, dextrin, etc.

The carbohydrates of the second and third classes bear the relation of *anhydrides* to the sugars of the first group.

The simple sugars of the formula $C_6H_{12}O_6$ are capable of direct alcoholic fermentation. This is particularly true of *dextrose* and *lævulose*, as well as of *maltose* among the saccharobioses. Technically, it is of the greatest importance that those saccharobioses and the polysaccharides which are *not* directly fermentable, can be converted by absorption of the elements of water into directly fermentable sugars.

Unorganized Ferments or Enzymes.—The breaking-down of saccharobioses and polysaccharides by absorption of water (*hydrolysis*) is induced by *enzymes*—albuminoid-like compounds, of which the most important of this class are *invertin* and *diastase.*

Invertin is produced in the yeast germ. It is soluble in water and has acquired its name from the fact that it is capable of converting sucrose into equimolecular quantities of dextrose and lævulose, known as *invert sugar.* At the same time the rotatory power of the liquid is reversed—it is *inverted.* Sucrose and dextrose are dextrorotatory, whereas lævulose deviates the plane of polarized light more strongly towards the left than an equivalent quantity of dextrose turns it to the right. Consequently, inversion changes a dextrorotatory sucrose solution into a lævo-rotatory solution of invert sugar:



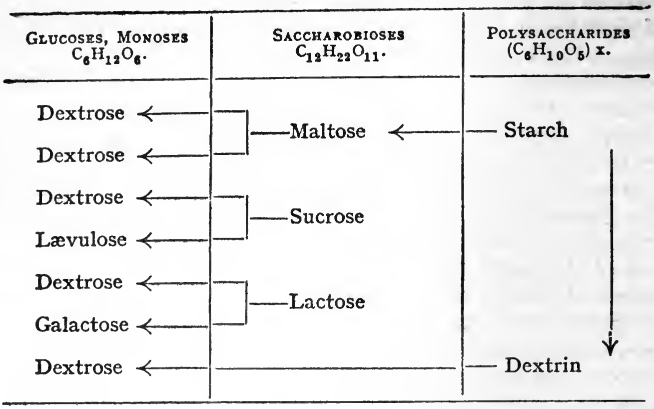
$$\underset{\text{Sucrose, dextro-rotatory.}}{C_{12}H_{22}O_{11}} \xrightarrow[\text{Invertin}]{H_2O} \left[\begin{array}{l} \rightarrow C_6H_{12}O_6\text{—Dextrose, dextro-rotatory} \\ \\ \rightarrow C_6H_{12}O_6\text{—Lævulose, lævo-rotary} \end{array}\right\} \begin{array}{c}\text{Invert}\\ \text{Sugar,}\\ \text{lævo-}\\ \text{rotatory.}\end{array}$$

Diastase is another unorganized ferment, produced in the germination of barley and other grains. The germination of the so-called *green malt* is stopped by killing the germ by rapid drying. The *malt* is then subjected to kiln-drying at a temperature which will not influence the activity of the diastase which, at 50° to 60°, can hydrolyze the starch. Two-thirds of the latter are changed to *maltose,* which can be directly fermented by yeast, whilst one-third is converted into *dextrin,* which is changed much more slowly by the diastase into dextrose.

Maltose, like sucrose, belongs to the saccharobioses. It takes up the elements of water and is resolved into dextrose. Lactose, also a saccharobiose, in the same way passes into a mixture of equimolecular quantities of galactose and dextrose. A review of these hydrolytic relations is shown in the diagram (p. 114).

The hydrolysis of the saccharobioses and of starch may also be brought about by warm, dilute sulphuric acid, whereby, for instance, starch is converted into dextrose and dextrin. In technical operations the preparation of saccharine juices from starchy compounds for the purpose of fermentation is carried out almost exclusively by the diastase of malt.

CARBOHYDRATES.



According to *Pasteur*, 94 to 95 per cent. of sugar changes to *alcohol* and *carbon dioxide* according to the equation:

$$C_6H_{12}O_6=2C_2H_6O+2CO_2.$$

Fusel oil, some *glycerol* (2–5 per cent.) and *succinic acid* (0·6 per cent.) are formed simultaneously, although the latter two substances appear generally towards the end of the fermentation (B. **27**, R. 671). The fusel oil contains n-propyl alcohol, isopropyl alcohol, isobutyl alcohol $(CH_3)_2CH.CH_2OH$, and especially amyl alcohol of fermentation—a mixtrue of isobutyl carbinol, $\begin{smallmatrix}CH_3\\CH_3\end{smallmatrix}\!>CH.CH_2.CH_2OH$, and optically active methyl ethyl carbin carbinol, $\begin{smallmatrix}CH_3.CH_2\\CH_3\end{smallmatrix}\!>{}^*CH.CH_2.OH$ (p. 120).

Not only the varieties of *Saccharomyces*, but also other budding fungi, *e.g. Mucor mucedo*, induce alcoholic fermentation. The various secondary fermentations occasioned by *Schizomycetes* are remarkable. It appears that the fusel oil (butyl and amyl alcohols) is produced by them in ordinary yeast fermentations. Later views and experiments lead to the view that fusel oil, as well as succinic acid, is not derived from the carbohydrates, but from the proteins (or their decomposition products—aminocaproic acid, aminovaleric acid, aminoglutaric acid), which arise partly from the material containing the sugar, and partly from the added yeast (C. 1905, II. 156; B. **39**, 3201). Alcoholic fermentation occurs without the agency of organisms in undamaged ripe fruits (grapes and cherries), when these are exposed for a period in an atmosphere of carbon dioxide.

Alcoholic Beverages.—The materials used in the preparation of alcoholic liquids by means of fermentation are:

1. *Saccharine plant juices.*
2. *Starch-containing substances*, seeds of grain and potatoes. The fermented liquids are directly consumed (*wine, beer*) or they are first distilled in order to produce the various kinds of *spirits*, the alcohol content of which may exceed 50 per cent.:

(1) By the fermentation of saccharine juices we obtain:

(*a*) *without* subsequent distillation:
From grapes: wine.
,, apples: cider.
,, currants: currant wine, etc.

(*b*) *with* subsequent distillation:
From wine: cognac.
,, molasses: rum.
,, cherries: "kirschwasser" (Baden).
,, prunes: sliwowitz (Bohemia), etc.

(2) By the fermentation of starch-containing substances, after converting the starch into sugar with malt;

(*a*) ***without*** subsequent distillation:
Barley: beer.
Wheat: weissbier (Berlin).
Rice: saké (Japan).

(*b*) *with* subsequent distillation:
Barley and rye, wheat or oats, and maize: corn whisky of various kinds.
Rice: arrac (East India).
Potatoes: potato spirit.

*Manufacture of Potato Spirit.**—Pure ethyl alcohol is obtained from potato spirit. The potatoes are first heated with steam to 140–150° C. under a pressure of from 2 to 3 atmospheres. The lower part of the apparatus is then opened and the potato mash pressed out and digested at 57–60° in a mashing apparatus with finely divided malt mixed with water. In this manner the starch of the potatoes is converted into sugar. When the ***mash*** has cooled to the proper temperature it is run into the fermentation-tubs, where it comes into contact with "pure culture" of yeast, and is then fermented. *Crude spirit* results from the distillation of the fermented mash; what remains is known as vinasse.

Manufacture of Pure Absolute Alcohol.—To purify the crude spirit further it is fractionated on a large scale in the column apparatus of *Savalle, Pistorius, Ilges.*† The first portions, more readily volatile, contain aldehyde, acetal, and other substances. A purer spirit (containing 95–96 per cent. of alcohol) follows, and in commerce is known as *spirit.* Finally come the *tailings,* in which are the fusel oils. To remove the latter, the spirit is diluted with water and passed through previously ignited wood-charcoal, which retains the fusel oils, and the filtrate is then distilled.

To prepare anhydrous alcohol, the rectified spirit (90–95 per cent. alcohol) is distilled with anhydrous potassium carbonate, anhydrous copper sulphate, quick-lime (A. **160**, 249), or barium oxide. Commercial "absolute" alcohol (about 99 per cent.) can be freed from its last traces of aldehyde and water, by treatment with alkali and silver oxide, and subsequent distillation over metallic calcium (B. **38**, 3612).

Detection of Water in Alcohol.—Absolute alcohol dissolves barium oxide, assuming a yellow colour at the same time, and does not restore the blue colour to anhydrous copper sulphate. It is soluble without turbidity in a little benzene; when more than three per cent. of water is present, cloudiness ensues. On adding anhydrous or absolute alcohol to a mixture of very little anthraquinone and some sodium amalgam it becomes dark green in colour, but in the presence of traces of water a red coloration appears (B. **10**, 927). Aqueous alcohol generates acetylene from calcium carbide, whilst the anhydrous spirit has no action in the cold (C. 1898, I. 658, 1225).

Detection of Alcohol.—Traces of alcohol in solutions are detected and determined either by oxidation to aldehyde (*q.v.*) or by converting it by means of dilute potassium hydroxide and iodine into iodoform (B. **13**, 1002).

Its conversion into ethyl benzoate, by shaking with benzoyl chloride and sodium hydroxide (B. **19**, 3218; **21**, 2744) also answers for this purpose.

Properties.—Absolutely pure alcohol is a mobile, colourless liquid with an agreeable ethereal odour. At the temperature of liquid air it is a thick liquid, and it solidifies to a varnish-like mass. It burns with a non-luminous flame and absorbs water energetically from the air. When mixed with water a contraction occurs, accompanied by rise of temperature; the maximum is reached when one molecule of alcohol is mixed with three molecules of water, corresponding with the formula $C_2H_6O+3H_2O$. The amount of alcohol in aqueous solutions is given either in per cent. by weight (degrees according to Richter) or per cent. by volume (degrees according to Tralles). It may be determined by an *alcoholometer,* the scale of

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* *Ferd. Fischer:* Hdb. d. chem. Technologie, 14. Aufl., 1893, S. 948.

† *Ibid.*, 15. Aufl., 1902, 2 Bd. p. 353.

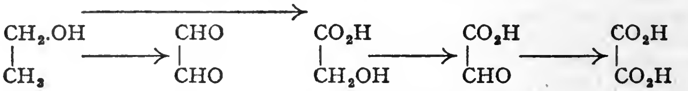
which gives directly the per cent. by weight or volume for a definite temperature (15° C.). Or the vapour tension is ascertained by means of the *vapourimeter* of Geissler, or the boiling point is determined with the *ebullioscope.*

The alcohol contained in spirituous beverages is first distilled off and then estimated in the distillate.*

Alcohol dissolves many mineral salts, the alkalies, hydrocarbons, resins, fatty acids, and almost all the carbon derivatives. The majority of gases are more readily soluble in it than in water; 100 volumes of alcohol dissolve 7 volumes of hydrogen, 25 volumes of oxygen, and 16 volumes of nitrogen.

Ethyl alcohol forms crystalline compounds with some salts, *e.g.* calcium chloride and magnesium chloride, in which it behaves analogously to water of crystallization.

Reactions.—Potassium and sodium dissolve in it, yielding the alcoholates. With sulphuric acid it yields ethyl sulphuric acid, and with sulphuric anhydride, carbyl sulphate (p. 83). Phosphorus bromide and iodide change it into ethyl bromide and ethyl iodide. Being a primary alcohol, such oxidants as manganese peroxide and sulphuric acid, chromic acid, platinum black and air, convert it to acetaldehyde and acetic acid (p. 102). Chlorine and bromine oxidize alcohol to acetaldehyde, which unites with more alcohol to form *acetal.* Chloral- and bromal-alcoholates are derived from acetal. Bleaching powder changes alcohol to chloroform, and iodine and potassium hydroxide convert it into iodoform. Nitric acid, free from nitrous acid, changes alcohol into ethyl nitrate (*q.v.*). Under certain conditions alcohol can be so oxidized by nitric acid that, besides attacking the $CH_2.OH$ group, the methyl group may be changed with the resulting formation of glyoxal, glycollic acid, glyoxalic acid, and oxalic acid:



$$\begin{tikzcd}
\begin{array}{l} CH_2.OH \\ | \\ CH_3 \end{array} \arrow[r] \arrow[rr, bend left] & \begin{array}{l} CHO \\ | \\ CHO \end{array} \arrow[rr, bend right] & \begin{array}{l} CO_2H \\ | \\ CH_2OH \end{array} \arrow[r] & \begin{array}{l} CO_2H \\ | \\ CHO \end{array} \arrow[r] & \begin{array}{l} CO_2H \\ | \\ CO_2H \end{array}
\end{tikzcd}$$

Ethyl Alcohol. Glyoxal. Glycollic Acid. Glyoxalic Acid. Oxalic Acid.

Mercury fulminate (*q.v.*) is produced when alcohol acts on mercury and an excess of nitric acid. Boiling with mercuric oxide and sodium hydroxide gives rise to a basic, explosive body, $C_2Hg_6O_4H_2$, called mercarbide (B. **33**, 1328).

If alcohol be passed through a red-hot tube, decomposition will be found to begin at 800°, and at 802–830°, about $\frac{1}{5}$ of it splits up into ethylene and water, and $\frac{4}{5}$ into aldehyde and hydrogen, whilst $\frac{2}{3}$ of the aldehyde further breaks down into methane and carbon monoxide (B. **34**, 3579). These decomposition products appear at lower temperatures by passing alcohol vapour over finely divided metals or aluminium oxide (C. 1903, I. 955: II. 335).

Alcoholates.—Sodium ethoxide is the most important alcoholate, as it is employed in a series of nucleus-synthetic reactions. It affords a means of splitting off water and alcohol. It may be prepared by dissolving sodium in alcohol, then heating it to 200° C. in an atmosphere of hydrogen to free it from alcohol, when it forms a white, voluminous powder (A. **202**, 294; B. **22**, 1010). Or, a calculated quantity of metallic sodium is added to a solution of alcohol in ether, toluene,

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* *Post:* Chemisch-technische Analyse, Braunschweig, 1881; *Böckmann,* Chem.-tech. Untersuchungsmethoden, Berlin, 1888; *König:* Chemie der menschlichen Nahrungs und Genussmittel; *Elsner:* Die Praxis des Chemikers bei Untersuchung von Nahrungsmitteln, etc., 1893.

or xylene, and the whole is heated under a reflux condenser until the sodium has entirely disappeared (B. **24**, 649; **37**, 2067). An excess of water changes the alcoholates to alcohol and sodium hydroxide; with a small amount of water the reaction is incomplete. The alcoholates also result on dissolving KOH and NaOH in strong alcohol. Sodium peroxide converts alcohol into sodium alcoholate and sodium hydrodioxide, NaO.OH (B. **27**, 2299).

Calcium Ethoxide, $Ca(OC_2H_5)_2$, is formed by the solution of metallic calcium in alcohol, or by the decomposition of calcium carbide by absolute alcohol with the aid of heat (B. **28**, R. 61; **38**, 3614).

Aluminium Ethoxide, $Al(OC_2H_5)_3$, m.p. 134°; b.p.$_{14}$ 205°; *Aluminium Propylate* $Al(OC_3H_7)_3$, m.p. 106°, b.p.$_{14}$ 248°, are remarkable in that they are volatile without decomposition under much reduced pressure. *Aluminium Methoxide* is decomposed by heat under reduced pressure. These compounds are prepared by the action of the respective alcohols on amalgamated aluminium (C. 1900, I. 10, 585).

Substituted Ethyl Alcohols:

1. $CH_2Cl.CH_2OH$	*Glycol Chlorhydrin* (Bromhydrin, Iodohydrin).	
2. $CHCl_2.CH_2OH$	*Dichlorethyl Alcohol*, b.p. 146° (B. **20**, R. 363).	
3. $CCl_3.CH_2OH$	*Trichlorethyl Alcohol*, m.p. 18°; b.p. 151° (A. **210**, 63).	
4. $CH_2NO_2.CH_2OH$	*Nitroethyl Alcohol.*	
5. $CH_2.NH_2.CH_2OH$	*Hydroxethylamine*	*Amidoethyl Alcohols.*
6. $CH_3.CH(NH_2)OH$	*Aldehyde Ammonia*	

The compounds 1, 4, and 5 will be discussed together with ethylene glycol, and 6 with acetaldehyde. Di- and trichlorethyl alcohols have been prepared by the interaction of zinc ethyl and di- and trichloracetaldehyde (p. 106), whilst trichlorethyl alcohol is formed from urochloralic acid (*q.v.*). The connection between the chlorinated ethyl alcohols and their oxygen compounds, whose chlorides they may be assumed to be, is seen in the following tabulation:—

Monochlorethyl Alcohol, $CH_2Cl.CH_2OH$, corresponds with $CH_2.OH.CH_2OH$—Glycol.
Dichlorethyl Alcohol, $CHCl_2.CH_2OH$, corresponds with $CHO.CH_2OH$—Glycolyl Aldehyde.
Trichlorethyl Alcohol, $CCl_3.CH_2OH$, corresponds with $COOH.CH_2OH$—Glycollic Acid.

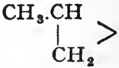
3. **Propyl Alcohols** [*Propanols*], $C_3H_7.OH$.—As explained in the introduction to the monohydric alcohols, two isomeric propyl alcohols are theoretically possible: the primary normal propyl alcohol and the secondary isopropyl alcohol. Their constitution is evident from their methods of formation and their reactions (p. 101).

Normal propyl alcohol, $CH_3.CH_2.CH_2.OH$, b.p. 97·4°; $D_{20} = 0{\cdot}8044$.
Isopropyl alcohol, $CH_3.CH(OH).CH_3$, b.p. 82·7°; $D_{20} = 0{\cdot}7887$.

Normal Propyl Alcohol occurs in fusel oil (*Chancel*, 1853) from which it is obtained by fractional distillation. It is an agreeable-smelling liquid, which is miscible in every proportion with water, but is insoluble in a saturated, cold calcium chloride solution, whereby it can be distinguished from ethyl alcohol. It can also be prepared from ethyl magnesium chloride and trioxymethylene (p. 106), and by reduction of propyl aldehyde. Oxidation converts it first to propyl aldehyde, and finally to propionic acid. By sulphuric acid it is converted into propylene, and by hydriodic acid into isopropyl iodide. This body is used for the preparation of isopropyl alcohol (p. 108), which can also be obtained by the reduction of its oxidation product, acetone.

Secondary or **Isopropyl Alcohol**, *Dimethyl Carbinol*, was prepared in 1855 by *Berthelot* from propylene and sulphuric acid (p. 104), and in 1862 by *Friedel,* from acetone. *Kolbe* (Z. Ch., 1862, 687) recognized in isopropyl alcohol the first representative of the class of secondary alcohols predicted by him (p. 101).

It may be obtained from propylene oxide,



$\begin{matrix}CH_3.CH\\ | \\ CH_2\end{matrix}\!>\!O$, by reduction; from formic ester by the aid of zinc and methyl iodide, and from acetaldehyde by means of methyl magnesium iodide (p. 106). Its formation from normal propylamine by the action of nitrous acid is noteworthy, and is accompanied by the simultaneous production of primary propyl alcohol and propylene.

The most practical method of obtaining it is to boil the iodide, which is easily prepared from glycerol, with ten parts of water and freshly prepared lead hydroxide in a vessel connected with a reflux condenser, or by simply heating the iodide with twenty volumes of water to 100° (A. **186**, 391). Oxidation changes it into acetone, whilst chlorine converts it into unsymmetric tetrachloracetone (*q.v.*).

Trichlorisopropyl Alcohol, $\begin{matrix}CCl_3\\CH_3\end{matrix}\!>\!CH.OH$, m.p. 49°, b.p. about 153°, is produced by the action of zinc methyl on chloral (p. 106) (A. **210**, 78).

4. **Butyl Alcohols,** $C_4H_9.OH$.—According to theory four isomerides are possible: 2 primary, 1 secondary, and 1 tertiary (p. 101):

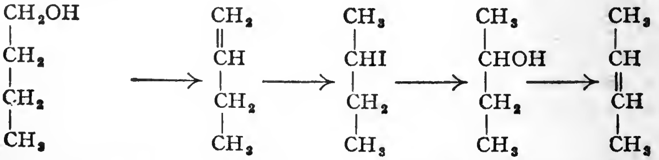
Name.	Formula.	M.P.	B.P.	Sp. Gr.
1. Normal Butyl Alcohol	$CH_3(CH_2)_2CH_2OH$	Liquid	116·8°	0·8099 at 20°
2. Isobutyl Alcohol . .	$(CH_3)_2.CH.CH_2OH$	,,	108·4°	0·8020 at 20°
3. Secondary Butyl Alcohol	$\begin{matrix}CH_3\,CH_2\\CH_3\end{matrix}\!>\!CH.OH$	,,	99°	0·8270 at 0°
4. Tertiary Butyl Alcohol	$(CH_3)_3C.OH$	25°	83°	0·7788 at 30°

Normal Butyl Alcohol, n-*Propyl Carbinol* [1-*Butanol*], is formed in the action of sodium amalgam on normal butyl aldehyde (Method 4*a*, p. 104), and from ethylene oxide and ethyl magnesium bromide (Method 6, p. 106). It is further produced by the fermentation of glycerol by a *schizomycetes* together with trimethylene glycol $CH_2[OH].CH_2CH_2[OH]$ (*Fitz*, B. **16**, 1438; **29**, R. 72).

Trichlorobutyl Alcohol, $CH_3.CHCl.CCl_2.CH_2.OH$, m.p. 62°; b.p.$_{45}$ 120°, results when zinc ethyl and butyl chloral (p. 106) are brought together, and is also obtained from urobutylchloralic acid (A. **213**, 372).

Secondary Butyl Alcohol, *Methyl Ethyl Carbinol, Butylene Hydrate,* [2-*Butanol*], is a strongly-smelling liquid. It is obtained from methyl ethyl ketone by reduction with sodium and water under ether (C. 1901, II. 1113); also from normal butyl alcohol by conversion into butylene—with the loss of water,—the addition of hydrogen iodide, and finally the hydrolysis of the iodide produced (p. 108). The same iodide is formed on heating erythritol $CH_2OH[CHOH]_2CH_2OH$ with hydriodic acid. Heated to 140–250°, it decomposes into water and β-butylene, $CH_3.CH:CH.CH_3$.

The genetic relations existing between the normal primary and secondary butyl alcohols, as well as between α-butylene and β-butylene, are shown in the following arrangement:—



Secondary butyl alcohol is the simplest *racemic* alcohol (comp. p. 55). It is resolved into its *optically active components* by means of the brucine salt of its acid sulphuric ester; but so far the two antipodes have not been obtained pure (B. **40**, 695).

Isobutyl Alcohol, *Isopropyl Carbinol, Butyl Alcohol of Fermentation* [*Methyl-2-propane-*1-*ol*], occurs in fusel oils and especially in the spirit from potatoes. It is a liquid possessing a characteristic odour. It may readily be changed to isobutylene $(CH_3)_2C{=}CH_2$, from which, by the addition of halogen acids, derivatives of tertiary butyl alcohol are obtained (p. 82). For the action of chlorine on isobutyl alcohol see B. **27**, R. 507; **29**, R. 922.

Tertiary Butyl Alcohol, *Trimethyl Carbinol,* [*Dimethyl-ethanol*], was prepared by *Butlerow* (A. **144**, 1) in 1863, from acetyl chloride and zinc methyl, and was the first representative of the tertiary alcohols predicted by *Kolbe.*

The oxidation of tertiary butyl alcohol produces isobutyric acid $(CH_3)_2.CH.CO_2H$ corresponding with isobutyl alcohol. This behaviour may be explained by the intermediate formation of isobutylene $(CH_3)_2C{=}CH_2$, the conversion of this, by water absorption, into isobutyl alcohol, and the oxidation of the latter (A. **189**, 73). The isobutylene, resulting from isobutyl alcohol and tertiary butyl alcohol, by the withdrawal of water can, by the addition of HClO and reduction of the resulting chlorhydrin, be changed to isobutyl alcohol, and by absorption of HI may be made to yield tertiary butyl iodide, which in turn may be transformed into tertiary alcohol (p. 108).

The boiling points of the haloid esters of the butyl alcohols will be given with those of the alkyl halides (p. 134).

Amyl Alcohols, $C_5H_{11}.OH$.—Theoretically, 8 isomers are possible: 4 primary alcohols, 3 secondary, and 1 tertiary, all of which are known.

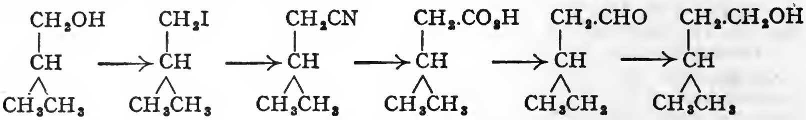
The following table contains the formulæ and the boiling points of the eight amyl alcohols. The name amyl alcohol is derived from ἄμυλον=starch, because the first-discovered amyl alcohol was observed in the fusel oil obtained from potato spirit.

Name.	Formula.	M.P.	B.P.$_{760}$
1. Normal Amyl Alcohol	$CH_3.[CH_2]_3CH_2.OH$		137°
2. **Isobutyl Carbinol**	$(CH_3)_2.CHCH_2.CH_2OH$		131°
3. **Active l-Amyl Alcohol**	$\begin{matrix}CH_3\\CH_3.CH_2\end{matrix}>\overset{*}{C}H.CH_2OH$		128°
4. Tertiary Butyl Carbinol	$(CH_3)_3C.CH_2OH$	+49°	112°
5. Diethyl Carbinol	$(CH_3CH_2)_2CH.OH$		116°
6. Methyl n-Propyl Carbinol	$\begin{matrix}CH_3\\CH_3.CH_2.CH_2\end{matrix}>\overset{*}{C}H.OH$		118°
7. Methyl Isopropyl Carbinol	$\begin{matrix}CH_3\\(CH_3)_2.CH\end{matrix}>\overset{*}{C}H.OH$		112°
8. **Dimethyl Ethyl Carbinol**	$\begin{matrix}(CH_3)_2\\CH_3.CH_2\end{matrix}>C.OH$	−12°	102·5°

Three of these eight alcohols contain an asymmetric carbon atom, indicated in the formulæ by a star, hence each can have three modifications, two optically active and one optically inactive (p. 31), which raises the possible number of amyl alcohols to fourteen. On the connection between boiling point and velocity of reaction, see B. **30**, 2784.

(1) **Normal Amyl Alcohol** is most easily prepared from normal amylamine which, in turn, is obtained from caproic acid. It is almost insoluble in water, and has an odour of fusel oil.

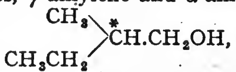
(2) **Isobutyl Carbinol,** $(CH_3)_2CH.CH_2.CH_2OH$, constitutes the chief ingredient of the amyl alcohol of fermentation obtained from fusel oil (p. 114), and occurs as esters of angelic and crotonic acids in Roman camomile oil. It may be obtained in a pure condition by synthesis from isobutyl alcohol, which it approaches in structure and with which it occurs in fusel oil:



A simpler synthesis is that from isobutyl magnesium bromide and trioxymethylene (Method 6, p. 106) (C. 1904, II. 1599). The so-called *alcohol of fermentation*, b.p. 129–132°, occurs in fusel oil and consists mainly of inactive isobutyl carbinol. It possesses a disagreeable odour. In addition, l-methyl ethyl carbin carbinol is present. It rotates the plane of polarization to the left, the activity being due to the presence of active amyl alcohol.

The different solubilities and crystalline forms of the barium salts of the two alcohols distinguish them and assist in their separation. From the more sparingly soluble salt, which forms in rather large quantity, isobutyl carbinol may be obtained (*Pasteur*). A more complete separation of the alcohols is reached by conducting HCl into the mixture; isobutyl carbinol will be esterified first, the active amyl alcohol remaining unchanged (*Le Bel*) (A. **220**, 149). A more suitable substance for separating the fermentation amyl alcohols by the esterification method is nitrophthallic acid (Vol. II.) (*Markwald*, B. **34**, 479; **37**, 1038). Oxidation of isobutyl carbinol gives inactive valeric acid, whilst l-methyl ethyl carbin carbinol yields the active form. When the crude fermentation alcohol is distilled with zinc chloride, ordinary *amylene* is the product, which consists mainly of $(CH_3)_2C{:}CH.CH_3$, resulting from a transposition of isobutyl carbinol; it contains, besides, γ-amylene and α-amylene (p. 85).

(3) **Active Amyl Alcohol,**



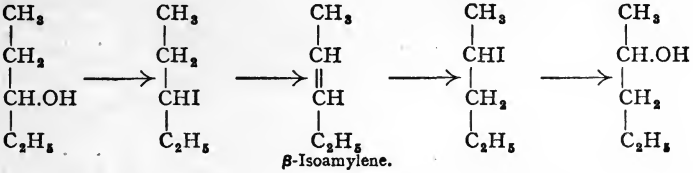
$$\begin{matrix} CH_3 \\ CH_3CH_2 \end{matrix}\!\!>\overset{*}{C}H.CH_2OH$$

sec.-Butyl Carbinol, Methyl Ethyl Carbin Carbinol. Of the two active modifications, the lævo-rotatory form, not yet obtained pure, is the optically active constituent of the fermentation alcohol. The proportion of the optically active alcohol in fermentation amyl alcohol varies from 13 to 58 per cent., according to the origin of the latter (B. **35**, 1596). Its rotatory power is $[\alpha]_D = -5{\cdot}9°$. The chloride, bromide, iodide, carbamic acid ester, and methyl ethyl acetic acid (see valeric acid) prepared from the lævo-carbinol, are all optically active and indeed dextro-rotatory, whilst the corresponding amine (p. 165) is lævo-rotatory (B. **28**, R. 410; **29**, 59).

The inactive modification of secondary butyl carbinol can be obtained by heating with sodium hydroxide (*Le Bel*), and also synthetically from secondary butyl magnesium bromide and trioxymethylene (p. 106; C. 1906, I. 130). Resolution by means of a mucor leaves the dextro-sec.-butyl carbinol (B. **15**, 1506).

(4) **Tertiary Butyl Carbinol,** $(CH_3)_3.C.CH_2OH$, is formed on reducing the chloride of trimethyl acetic acid or pivalic acid (B. **24**, R. 557) with sodium amalgam. Nitrous acid converts its amine, in consequence of a remarkable rearrangement of atoms, into dimethyl ethyl carbinol (B. **24**, 2161).

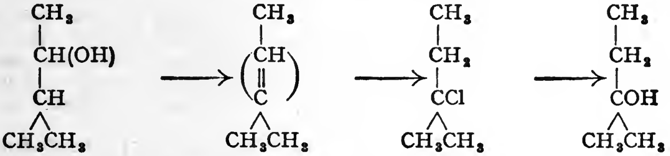
(5) **Diethyl Carbinol,** $(C_2H_5)_2.CHOH$, is formed by the action of zinc and ethyl iodide upon ethyl formate. Since β-amylene, $C_2H_5.CH:CH.CH_3$, yields the iodide of methyl n-propyl carbinol with HI, from which methyl normal propyl carbinol is obtained, the diethyl carbinol can thus be converted into the latter alcohol:



The two methyl propyl carbinols are obtained from methyl-n-propyl ketone and methyl isopropyl ketone by reduction with sodium amalgam.

(6) **Methyl n-Propyl Carbinol,** $CH_3.CH_2.CH_2.\overset{*}{C}H(OH).CH_3$, is resolved by *Penicillium glaucum* (*Le Bel*); the dextro-rotatory modification is destroyed, and the lævo-rotatory form remains.

(7) **Methyl Isopropyl Carbinol,** $(CH_3)_2.CH.CH(OH).CH_3$, yields the derivatives of tertiary amyl alcohol, apparently with the intermediate formation of amylene, $(CH_3)_2C{=}CHCH_3$, when acted on by halogen acids and also PCl_5:



The true derivatives of methyl isopropyl carbinol are obtained from α-isoamylene $(CH_3)_2.CH.CH:CH_2$ (p. 185), by the addition of halogen acids, at ordinary temperatures or when warmed.

(8) **Tertiary Amyl Alcohol,** ${}^{(CH_3)_2}_{C_2H_5}{>}C.OH$, *Dimethyl Ethyl Carbinol, Amylene Hydrate*, is a liquid with an odour like that of camphor. It produces sleep, the same as does chloral hydrate, and is, therefore, produced technically.

Amyl alcohol of fermentation is employed as the parent substance, which, with zinc chloride, yields ordinary amylene, consisting mainly of β-isoamylene, $CH_3CH{=}C{<}^{CH_3}_{CH_3}$ (p. 185). This is shaken at −20° with sulphuric acid diluted with ½–1 volume of water, and the solution is boiled with water (A. **190**, 345).

It is further formed by the action of nitrous acid on the amine of tertiary butyl carbinol (B. **24**, 2519), and from propionyl chloride and zinc methyl. At 200° it decomposes into water and β-isoamylene.

HIGHER HOMOLOGUES OF THE SATURATED ALCOHOLS, $C_nH_{2n+1}.OH$

There are many representatives of the higher homologues of the alcohols of this series. Fourteen of the seventeen theoretically possible hexyl alcohols and thirteen of the thirty-eight predicted heptyl alcohols have been prepared. The higher we ascend in the series, the larger the number of theoretically possible members and the smaller the number of those alcohols which are actually known. Only a few of them are noteworthy either from a point of formation, structure, or occurrence in the animal or vegetable kingdoms. In the following table will be found the names, formulæ, melting points, and boiling points mainly of normal alcohols :—

Name.	Formula.	M.P.	B.P.
n-Hexyl Alcohol	$CH_3.[CH_2]_4CH_2.OH$	. .	157°
Pinacolyl Alcohol	$(CH_3)_3C.CH(CH_3\ OH$	+4°	120°
Sym.-Tetramethyl Ethyl Alcohol .	$(CH_3)_2CH.C(CH_3)_2OH$	−10·5°	119°
n-Heptyl Alcohol	$CH_3[CH_2]_5CH_2OH$	. .	175°
Pentamethyl Ethyl Alcohol . .	$(CH_3)_3C.C(CH_3)_2OH$	+17°	131°
n-Octyl Alcohol	$CH_3.[CH_2]_6.CH_2OH$	. .	199°
Cetyl Alcohol or Ethal	$CH_3[CH_2]_{14}.CH_2OH$	+49·5°	340°
Ceryl Alcohol or Cerotin . . .	$C_{26}H_{53}.OH$	79°	. .
Melissyl or Myricyl Alcohol . .	$C_{30}H_{61}.OH$	85°	. .

n-Hexyl Alcohol occurs as acetic and butyric esters in the oil of the seed of *Heracleum giganteum* (A. **163**, 193).

Pinacolyl Alcohol has a camphor-like odour. It results from the reduction of pinacolin (*q.v.*) or tert.-butyl methyl ketone, $(CH_3)_3.C.CO.CH_3$. (See B. **26**, R. 14; C. 1901, II. 1157; comp. Tetramethyl Ethylene.) The isomeric sym.-*Tetramethyl Ethyl Alcohol* is prepared from acetone and isopropyl magnesium bromide. It decomposes when heated with dilute sulphuric acid into H_2O and tetramethyl ethylene (C. 1906, II. 1718).

n-*Heptyl Alcohol* has been prepared from œnanthol (*q.v.*) by reduction, and from n-heptane (A. **161**, 278). *Pentamethyl Ethyl Alcohol* has been obtained by various syntheses by means of magnesium-organic compounds (C. 1906, II. 1718).

n-*Octyl Alcohol*, $C_8H_{17}OH$, occurs as acetic ester in the volatile oil of *Heracleum spondylium*, as butyric ester in the oil of *Pastinaca sativa*, and in the oil of *Heracleum giganteum* (A. **185**, 26). It has been obtained artificially by several methods, amongst others by the reduction of caprylic ester by sodium and alcohol (Method 4*a*, p. 104).

Cetyl Alcohol, Hexadecyl Alcohol, *Ethal*, $C_{16}H_{33}.OH$, is a white, crystalline mass. It was prepared in 1818 by *Chevreul* from the cetyl ester of palmitic acid, the chief ingredient of *spermaceti* (see palmitic acid), by saponification with alcoholic potassium hydroxide:

$$\begin{matrix}C_{16}H_{31}O\\C_{16}H_{33}\end{matrix}\!\!>\!O+KOH=\underset{\substack{\text{Cetyl}\\\text{Alcohol.}}}{C_{16}H_{33}.OH}+\underset{\substack{\text{Potassium}\\\text{Palmitate.}}}{C_{15}H_{31}COOK.}$$

When fused with potassium hydroxide, it yields palmitic acid (p. 109):

$$C_{15}H_{31}CH_2OH+KOH=C_{15}H_{31}COOK+2H_2.$$

Ceryl Alcohol, *Cerotin*, $C_{26}H_{53}.OH$, as ceryl cerotic ester, $C_{26}H_{51}O.OC_{26}H_{53}$ (B. **30**, 1418), constitutes Chinese wax. It is obtained by melting the latter with potassium hydroxide, the prolonged action of which produces cerotic acid.

Melissyl Alcohol, *Myricyl Alcohol*, $C_{30}H_{61}.OH$, occurs as myricyl palmitate in beeswax, from which it is isolated in the same manner as the preceding compound. *Chloride*, m.p. 64°; *iodide*, m.p. 69·5°. Myricyl iodide and metallic sodium give *Hexacontane*, $C_{60}H_{122}$, or *Dimyricyl* (p. 76).

B. UNSATURATED ALCOHOLS

I. OLEFINE ALCOHOLS, $C_nH_{2n-1}.OH$

These are derived from the unsaturated alkylenes, C_nH_{2n}, in the same manner as the normal alcohols are obtained from their hydrocarbons. In addition to the general character of alcohols, they possess the property of the olefines to form addition compounds.

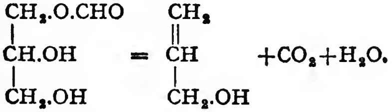
The chief representative of the class is allyl alcohol, $CH_2=CHCH_2OH$. When oxidized by potassium permanganate, the double linkage of the allyl alcohols is severed, and trihydric alcohols—glycerols—result (B. **21**, 3347).

1. **Vinyl Alcohol**, *Vinol*, $CH_2:CH.OH$, separates as a mercury oxychloride compound, $C_2H_3O_2Hg_3Cl_2$, from ethyl ether—a small quantity of which is always retained—on the addition to it of an alkaline mercury monoxychloride solution (*Poleck* and *Thümmel*, B. **22**, 2863). It is produced simultaneously with hydrogen peroxide when ether is oxidized with atmospheric oxygen. It cannot be separated from its mercury derivative because all reactions by which it should be produced yield the isomeric acetaldehyde, $CH_3.CHO$ (p. 37). It seems to be the universal rule that the atomic grouping $=C:CH.OH$, in the act of formation, is transposed into $=CH.CHO$ (*Erlenmeyer, Sr.*, B. **13**, 309; **14**, 320); however, there are stable compounds in which the groupings $=C=CHOH$ and $=C=C(OH)R$ (see Hydroxy-methylene Ketone, p. 343) are present.

The haloid esters of vinyl alcohol are to be considered as being the monohalogen substitution products of ethylene (p. 97). Vinyl ether, vinyl ethyl ether, vinyl sulphide, vinyl or ethylene sulphuric acids, are known (p. 147). The radical ***vinyl*** is present in neurine, so important physiologically, and also in vegetable alkaloids (*q.v.*).

2. **Allyl Alcohol** [*Propenol*-3], $C_3H_5.OH = CH_2:CH.CH_2.OH$.—Solidifies −50°, b.p. 96–97°, $D_{20} = 0{\cdot}8540$. Allyl compounds occur in the vegetable kingdom: allyl sulphide and diallyl trisulphide (C. 1892, II. 833), in oil of garlic, and allyl thiocyanate, $C_3H_5N=C=S$, in oil of mustard. It may be prepared (1) by heating allyl iodide—which is easily prepared from glycerol—to 100° with 20 parts water; (2) it is produced, also, when nascent hydrogen acts on acroleïn, $CH_2:CH.COH$, and (3) sodium on dichlorhydrin, $CH_2Cl.CHCl.CH_2OH$ (B. **24**, 2670). (4) It is best obtained from glycerol by heating the latter with formic or oxalic acid (A. **167**, 222).

In this reaction the oxalic acid at first breaks down into carbon dioxide and formic acid, which forms an ester with the glycerol; this then decomposes into allyl alcohol, carbon dioxide, and water:



$$\begin{array}{lcll} CH_2.O.CHO & & CH_2 & \\ | & & \| & \\ CH.OH & = & CH & +CO_2+H_2O. \\ | & & | & \\ CH_2.OH & & CH_2.OH & \end{array}$$

Allyl alcohol is a mobile liquid with a pungent odour; it is miscible with water, and burns with a bright flame.

It yields acroleïn and acrylic acid when oxidized with silver oxide, and only *formic acid* (no acetic) with chromic acid. *Glycerol* results when potassium permanganate is the oxidant (B. **21**, 3351). Nascent hydrogen attacks it with difficulty, as seems to be indicated by its formation from acroleïn. Boiling with zinc and sulphuric acid (B. **7,** 856), however, or with aluminium and potassium hydroxide solution (C. 1899, II. 181) causes the formation of a small quantity of n-propyl alcohol; reduction with sodium-ammonium yields propylene (C. 1906, II. 670). Chlorine acts partly as an oxidizing, and partly as an additive reagent, giving rise to acroleïn and dichlorhydrin (B. **24,** 2670). When heated to 150° with potassium hydroxide, formic acid, n-propyl alcohol, and other products are formed.

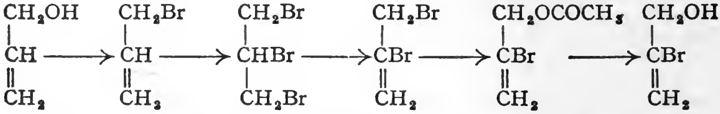
Allyl alcohol, when heated with mineral acids, yields propionic aldehyde and methyl ethyl acroleïn (B. **20,** R. 699).

Mercuric salts form compounds with it, which dissolve with difficulty (B. **33,** 2692).

Halogen-substituted Allyl Alcohols have been obtained from α- and β-dichloropropylene and β-dibromopropylene.

α-Chlorallyl Alcohol, $CH_2{=}CCl.CH_2OH$, b.p. 136°.
β-Chlorallyl Alcohol, $CHCl{=}CH.CH_2OH$, b.p. 153°.
α-Bromallyl Alcohol, $CH_2{=}CBr.CH_2OH$, b.p. 152°.

Sulphuric acid, acting on α-chlorallyl alcohol, produces acetone-alcohol (*q.v.*), and with α-bromallyl alcohol yields propargyl alcohol (see p. 125). α-Bromallyl alcohol may be prepared from allyl alcohol by a series of reactions, shown in the following diagram:—



3. *β-Allyl Alcohol,* $CH_2{=}C(OH).CH_3$, is only known in the form of its ether (p. 129). *Sodium β-allyl Alcoholate* is produced by the action of metallic sodium upon acetone (A. **278,** 116), diluted with anyhdrous ether.

4. **Crotonyl Alcohol,** $CH_3.CH{:}CH.CH_2OH$, b.p. 117–120°, is obtained from crotonaldehyde, $CH_3.CH{:}CH.CHO$, by means of nascent hydrogen.

The *Higher Olefine Alcohols* are synthetically prepared by means of the zinc and magnesium organic compounds (p. 106): (1) from olefine aldehydes and zinc alkyls or magnesium alkyl halides; or (2) from aldehydes or ketones with zinc and allyl iodide (B. **17,** R. 316; **27,** 2434; A. **185,** 151, 175; **196,** 109; J. pr. Ch. [2] **30,** 399; C. 1901, I. 668, 997; II. 622; 1907, I. 96). (3) Many aldehydes and ketones, when boiled with acid chlorides, especially benzoyl chloride, yield the benzoic ester of the olefine alcohols, isomeric with the ketones, *e.g.* $C_5H_{11}.CH{:}CHO.COC_6H_5$ from œnanthic aldehyde (p. 201)and benzoyl chloride; $C_9H_{10}C({:}CH_2)O.COC_4H_9$ from methyl nonyl ketone and valeryl chloride (C. 1913, I. 71). (4) *αβ*-olefine carboxylic esters are reduced by sodium and alcohol to saturated alcohols (see *4a*, p. 104); on the other hand, carboxylic esters containing a remote olefine group, as in the case of allyl acetic acid, oleic acid, undecylic acid ester, etc., yield the corresponding olefine alcohols when similarly reduced (C. 1905, I. 25; II. 1700).

2, 4-Pentenol, $CH_3.CH{=}CH.CH(OH)CH_3$.

Dimethyl Allyl Carbinol, $CH_2{=}CH.CH_2C(CH_3)_2OH$, b.p. 119·5°. *Diethyl Allyl Carbinol,* b.p. 156°. *Methyl Propyl Allyl Carbinol,* b.p. 159–160°.

1,11-*Undecylenol* $CH_2{:}CH[CH_2]_8CH_2OH$, b.p.$_{15}$ 133° and *Oleic Alcohol* $C_{18}H_{36}O$, b.p.$_{18}$ 207°, are obtained from undecylenic ester and oleic ester by reduction.

UNSATURATED ALCOHOLS, $C_nH_{2n-3}.OH$

To this class belong:

Alcohols containing a pair of trebly linked carbon atoms, and *alcohols* which contain two pairs of doubly linked carbon atoms. Propargyl alcohol is the only well-known member of the *acetylene series*, whereas various alcohols, derived from *diolefines*, have not only been synthetically prepared, but have also been discovered in ethereal oils.

2. ACETYLENE ALCOHOLS

Propargyl Alcohol [*Propinol*-3], $CH : C.CH_2OH$, b.p. 114°, $D_{20} = 0{\cdot}9715$.—This alcohol was obtained by *Henry* in 1872 (B. **5**, 569; **8**, 389) upon treating *a*-bromallyl alcohol (see p. 124) with potassium hydroxide. It is a mobile, agreeable smelling liquid. Like acetylene, it forms an explosive silver compound, $C_3H_2(OH)Ag$, white in colour. The copper salt $(C_3H_2OH)_2Cu$, is a yellow precipitate.

Homologous acetylene alcohols result from the action of sodium compounds of the alkyl acetylenes on trioxymethylene or another aldehyde (C. 1902, I. 629):

$$RC : CNa + R'.CHO = RC : CCH\ (ONa)\ R'.$$

Amyl Propiolic Alcohol, $CH_3[CH_2]_4C{\equiv}C.CH_2OH$, b.p.$_{13}$ 98°.

3. DIOLEFINE ALCOHOLS

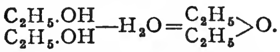
Higher alcohols, in which the double union of carbon atoms occurs twice, are synthetically produced by the action of zinc and allyl iodide on esters of formic acid and acetic acid (A. **197**, 70). *Diallyl Carbinol* $(CH_2{:}CH.CH_2)_2CHOH$, b.p. 151°. *Diallyl Methyl Carbinol* $(CH_2{:}CH.CH_2)_2, C(CH_3)OH$, b.p. 158°. *Diallyl Ethyl Carbinol* $(CH_2{:}CH.CH_2)_2C(C_2H_5)OH$, b.p. 175°. *Diallyl Propyl Carbinol* $(CH_2{:}CH.CH_2)_2(C_3H_7)OH$, b.p. 194° (C. 1901, I. 997).

Diolefine alcohols, which can be converted into terpenes, are of great theoretical interest; such are geraniol or rhodinol, and linalool. They will be discussed under the olefinic terpene or terpenogen group (Vol. II.).

ALCOHOL DERIVATIVES

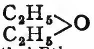
1. SIMPLE AND MIXED ETHERS

Ethers are the *oxides of the alcohol radicals*. If the alcohols are compared with basic hydroxides, then the ethers are analogous to the metallic oxides. They may be considered also as anhydrides of the alcohols, formed by the elimination of water from two molecules of alcohol:



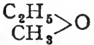
$$\begin{matrix}C_2H_5.OH\\C_2H_5.OH\end{matrix} - H_2O = \begin{matrix}C_2H_5\\C_2H_5\end{matrix}{>}O.$$

Ethers containing two similar alcohol radicals are termed *simple ethers*; those with different radicals, *mixed ethers*:



$$\begin{matrix}C_2H_5\\C_2H_5\end{matrix}{>}O$$

Ethyl Ether, or Diethyl Ether.

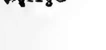


$$\begin{matrix}C_2H_5\\CH_3\end{matrix}{>}O$$

Methyl Ethyl Ether.

The metamerism of ethers among themselves is dependent upon the homology of the alcohol radicals, which are united by the oxygen atom (p. 26).

We must make a distinction between the above and the so-called compound ethers or *esters*, in which both an alcohol radical and an acid radical are present—*e.g.*:



$$\begin{matrix}C_2H_5\\C_2H_3O\end{matrix}{>}O$$

Ethyl Acetic Ester; and

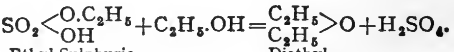
$$\begin{matrix}C_2H_5\\NO_2\end{matrix}{>}O$$

Ethyl Nitric Ester;

The properties of these substances are entirely different from those of the alcohol ethers, and in the following pages they will always be termed *esters*.

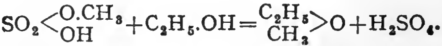
The following are the more important methods of preparing the ethers:

1. The chief method of formation consists of the interaction of *sulphuric acid* and *alcohols*. Alkyl sulphuric acids result at first, but on further heating with alcohols these are converted into ethers. This procedure affords a means of obtaining both simple and mixed ethers (*Williamson, Chancel*):



$$SO_2<\begin{matrix}O.C_2H_5\\OH\end{matrix}+C_2H_5.OH=\begin{matrix}C_2H_5\\C_2H_5\end{matrix}>O+H_2SO_4.$$

Ethyl Sulphuric Acid. Diethyl Ether.



$$SO_2<\begin{matrix}O.CH_3\\OH\end{matrix}+C_2H_5.OH=\begin{matrix}C_2H_5\\CH_3\end{matrix}>O+H_2SO_4.$$

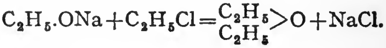
Methyl Sulphuric Acid. Methyl Ethyl Ether.

When a mixture of two alcohols reacts with sulphuric acid, three ethers are simultaneously formed; two are simple and one is a mixed ether. Subsidiary reactions give rise to the production of sulphones and sulphonic acids (C. 1897, II. 340; 1899, II. 30). Other polybasic acids, such as phosphoric, arsenic, and boric, behave like sulphuric acid. This is also true of hydrochloric acid at 170°, and sulpho-acids—*e.g.* benzene sulphonic acid, at 145° (*F. Krafft*, B. **26**, 2829). In this reaction ethyl benzene sulphonic ester is produced and breaks down according to the equations:

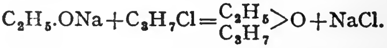
$$C_6H_5SO_3H+C_2H_5OH=C_6H_5SO_3C_2H_5+H_2O.$$
$$C_6H_5SO_3C_2H_5+C_2H_5OH=C_6H_5SO_3H+(C_2H_5)_2O.$$

The dialkyl sulphates are converted by alcohols into ethers and alkyl sulphuric acids much more quickly than the alkyl sulphuric acids (C. 1907, I. 702).

2. The action of the alkylogens on the sodium alcoholates in alcoholic solution produces mixed ethers.



$$C_2H_5.ONa+C_2H_5Cl=\begin{matrix}C_2H_5\\C_2H_5\end{matrix}>O+NaCl.$$



$$C_2H_5.ONa+C_3H_7Cl=\begin{matrix}C_2H_5\\C_3H_7\end{matrix}>O+NaCl.$$

Consult B. **22**, R. 381, 637, upon the velocity of these reactions.

3. Halogen-substituted ethers yield homologous ethers on reaction with zinc or magnesium organic compounds, *e.g.* bromomethyl amyl ether (p. 186) and ethyl magnesium bromide yield amyl propyl ether (C. 1904, I. 1195):

$$C_5H_{11}OCH_2Br+BrMgC_2H_5=C_5H_{11}OC_3H_7+MgBr_2.$$

4. Action of the alkylogens on metallic oxides, especially silver oxide:

$$2C_2H_5I+Ag_2O=(C_2H_5)_2O+2AgI$$

indicates the constitution of the ethers.

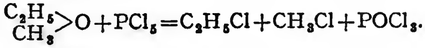
Properties.—Ethers are neutral, volatile (hence the name αἰθήρ, air) bodies, nearly insoluble in water. The lowest members are gases; the next higher are liquids, and the highest—*e.g.* cetyl ether—are solids. Their boiling points are very much lower than those of the corresponding alcohols (A. **243**, 1).

Reactions.—Chemically, ethers are very indifferent, because all the hydrogen is attached to carbon.

(1) When oxidized they yield the same products as their alcohols.

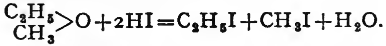
(2) They yield ethereal salts when heated with concentrated sulphuric acid.

(3) Phosphorus chloride converts them into alkyl chlorides:



$$\begin{matrix}C_2H_5\\CH_3\end{matrix}\!>O+PCl_5=C_2H_5Cl+CH_3Cl+POCl_3.$$

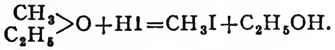
(4) The same occurs when they are heated with the haloid acids, especially with HI at 100° (C. 1897, II. 408; 1901, II. 679):



$$\begin{matrix}C_2H_5\\CH_3\end{matrix}\!>O+2HI=C_2H_5I+CH_3I+H_2O.$$

In the cold the effect of the HI is to cause decomposition into alcohol and iodide, and in the case of mixed methyl alkyl ethers the production of methyl iodide and alkyl alcohol predominates. If the alkyl group is a tertiary one, the iodo-tert-alkyl mainly is produced; but in other cases a mixture of the two possible iodides and alcohols results (B. **39**, 2569).

$$\begin{matrix}CH_3\\C_2H_5\end{matrix}\!>O+HI=CH_3I+C_2H_5OH.$$



(5) Many ethers, especially those containing secondary and tertiary, or unsaturated (allyl) groups, are broken down into alcohols when heated with water or very dilute sulphuric acid at 150° (B. **10**, 1903); *e.g.* vinyl ethyl ether decomposes into alcohol and aldehyde (B. **39**, 1410 footnote).

(6) Ether combines with many substances to form *addition compounds*, as, for example, with magnesium or zinc iodide, magnesium alkyl halides (p. 185) producing bodies of the type $2R_2O.MgI_2$, $R_2O.MgIR'$, etc. This is due to the presence of a tetravalent *oxonium* oxygen atom (*Baeyer* and *Villiger*, B. **34**, 2688).

With benzoyl chloride (Vol. II.) the ether magnesium iodide breaks up into ethyl iodide, ethyl benzoate and $MgCl_2$ (C. 1905, I. 1082; B. **38**, 3665):

$$2(C_2H_5)_2O.MgI_2+2C_6H_5COCl=2C_2H_5I+2C_6H_5CO.OC_2H_5+MgCl_2.$$

A. ETHERS OF THE SATURATED OR PARAFFIN ALCOHOLS

Methyl Ether, $(CH_3)_2O$, is prepared by heating methyl alcohol with sulphuric acid (B. **7**, 699). It is an agreeable-smelling gas, which may be condensed to a liquid at about −23°. Water dissolves 37 volumes and sulphuric acid upwards of 600 volumes of the gas.

Chlorine converts methyl ether into chloromethyl ether, sym.-dichloromethyl ether, and perchloromethyl ether which partially decomposes on boiling. The first two are formaldehyde derivatives, and, together with the corresponding bromo- and iodo-compounds, will be treated after formaldehyde.

Ethyl Ether or Ether, $(C_2H_5)_2O$, m.p. −113° (B. **33**, 638), b.p. 35°, $D_0 = 0{\cdot}736$, is by far the most important representative of this class of compounds. It has been known for a long time.

History.—Ethyl ether and its production from alcohol and sulphuric acid were known and described by *Valerius Cordus*, a German physician, in the sixteenth century. Until the beginning of the present century ether was regarded as a sulphur-containing body; hence, to distinguish it from other ethereal compounds, it was called *sulphur-ether*. The ether process, in which a comparatively small quantity of sulphuric acid was capable of converting a large quantity of alcohol into ether, was included in the category of *catalytic reactions*. The explanation of this process constitutes one of the most important advances in organic chemistry.

In 1842, *Gerhardt*, from purely theoretical reasons and in opposition to *Liebig*, concluded that the ether molecule did not contain the same number of carbon atoms as were present in the alcohol molecule, but *twice* that number. He was unable to gain general acceptance for this view. *Williamson*, in 1850, by a new synthesis of ether, proved the correctness of *Gerhardt's* conception, not only for it, but for ethers in general; he caused reaction to take place between sodium ethoxide and ethyl iodide (p. 126). The formation of ether from alcohol and sulphuric acid *Williamson* explained by a continuous breaking-down and re-formation of ethyl sulphuric acid, made possible by the contact of alcohol with the acid at 140° (A. **77**, 37; **81**, 73).

Chancel, who preceded *Williamson* in publication, had made ether independently of the latter, by heating a mixture of potassium ethyl sulphate and potassium ethoxide:

$$SO_4\begin{cases}C_2H_5\\K\end{cases}+O\begin{cases}C_2H_5\\K\end{cases}=SO_4\begin{cases}K\\K\end{cases}+O\begin{cases}C_2H_5\\C_2H_5\end{cases}$$

The objection that ether, because of its low boiling temperature, could not contain the double number of carbon atoms in its molecule, *Chancel* removed by citing the boiling point of ethyl acetic ester (*Laurent* and *Gerhardt*, Cr. 1850, **6**, 369).

Ethyl Alcohol	C_2H_5OH	b.p. 78°.
Ether	$(C_2H_5)_2O$	b.p. 35°.
Acetic Acid	CH_3CO_2H	b.p. 118°.
Ethyl Acetic Ester	$CH_3CO_2C_2H_5$	b.p. 77°.

Thus it was proved that ethyl alcohol and ether were bodies belonging to the *water type* (p. 19)—*i.e.* they might be regarded as water in which one and two hydrogen atoms were replaced by ethyl:

$$\left.\begin{matrix}H\\H\end{matrix}\right\}O \qquad \left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O \qquad \left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O.$$

Preparation.—Ether is made (1) from ethyl alcohol and sulphuric acid heated to 140°. The process is continuous. (2) From benzene sulphonic acid and alcohol at 135–145° (B. **26**, 2829).

The advantage in the second method is that the ether is not contaminated with sulphur dioxide, which in the first method has to be removed from the crude product by washing with a soda solution. Anhydrous ether may be obtained by distilling ordinary ether over quicklime, and drying it finally with sodium wire (see aceto acetic ester) until there is no further evolution of hydrogen.

Test for Water and Alcohol.—When ether containing water is shaken with an equal volume of CS_2, a turbidity results. When alcohol is present, the ether, on shaking with aniline violet, is coloured; anhydrous ether does not acquire a colour when similarly treated.

Properties.—Ethyl ether is a mobile liquid with peculiar odour. It dissolves in 10 parts of water and is miscible with alcohol. Nearly all the carbon compounds insoluble in water, such as the fats and resins, are soluble in ether. It is extremely inflammable, burning with a luminous flame. Its vapour forms a very explosive mixture with air. When inhaled, ether vapour brings about unconsciousness, a property discovered in 1842 by *Charles Jackson*, of Boston,* and has been used in surgery since *Morton's* employment of it in 1846. *Hoffmann's Anodyne, Spiritus Aethereus* (so named after the great Halle clinician, who died in 1742) is a mixture of 3 parts alcohol and 1 part ether.

Ether unites with bromine to form peculiar, crystalline addition products somewhat like the so-called bromine hydrate; it combines, too, with water, metallic salts, hydroferrocyanic acid, etc. (see above, p. 127).

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* Der Aether gegen den Schmerz, von Binz, Bonn, 1896.

Reactions.—For the action of air on ether, see vinyl alcohol (p. 123). Slow combustion leads to the formation of diformaldehyde peroxide hydrate. Hydrogen peroxide is produced when oxygen acts on moist ether (B. **29**, R. 840; **38**, 1409). When heated with water and sulphuric acid to 180°, ethyl alcohol results. When ozone is conducted into anhydrous ether, an explosive peroxide is formed.

Chlorine, acting on cooled ether, produces (A. **279**, 301):

Monochlorether, $CH_3.CHCl.O.C_2H_5$, b.p. 98°.
1,2-Dichlorether, $CH_2Cl.CHCl.O.C_2H_5$, b.p. 145°.
Trichlorether, $(CHCl_2.CHCl.O.C_2H_5$, b.p. 170–175° (C. 1904, I. 920).
Perchlorether, $(C_2Cl_5)_2O$, m.p. 68°, breaks down on distillation into C_2Cl_6 and trichloracetyl chloride, $C_2Cl_3O.Cl$. The α-halogen substituted ethers are closely connected with the aldehyde alcoholates (p. 204).

2-Chloro-, Bromo-, Iodo-ethyl Ethers are the ethers of glycol chloro-, bromo-, and iodo-hydrins—*e.g.* $CH_2Cl.CH_2O.C_2H_5$.

sym.-*Dichlorether*, $CH_3.CHCl.O.CHCl.CH_3$, b.p. 116°, is produced by the action of hydrochloric acid on aldehyde.

sym.-*Di-iodoether* $(I.CH_2.CH_2)_2O$. (See Glycol Halogen Ester.)

The following table contains the melting and boiling points of the better known simple and mixed ethers:—

Ethyl Methyl Ether	b.p. 11°	*n-Propyl Methyl Ether*	b.p. 37°
Methyl tert.-Butyl Ether	b.p. 54°	*Methyl Isopropyl Ether*	b.p. 32°
n-Propyl Ether	b.p. 90°	*Isopropyl Ether*	b.p. 70°
Ethyl tert.-Butyl Ether	b.p. 70°	*Isopropyl tert.-Butyl Ether*	b.p. 75°
Isoamyl Ether	b.p. 160°	*Cetyl Ether* $(C_{16}H_{33})_2O$, m.p. 55°	b.p. 300°

The majority of these ethers are produced by the interaction of alkyl halides and sodium alcoholates (C. 1903, I. 119; 1904, I. 1065); n-propyl ether is formed from n-propyl alcohol and ferric chloride, at 145–155° (C. 1904, II. 18). *Methyl* tert.-*Amyl Ether*, $(OH_3)_2C(OCH_3).CH_2CH_3$, b.p. 86°, is prepared from trimethyl ethylene by heating it with methyl alcohol and iodomethane (C. 1907, I. 1125).

B. ETHERS OF UNSATURATED ALCOHOLS

It was explained, when discussing the unsaturated alcohols (p. 123), that the members of that series in which hydroxyl was combined with a doubly linked carbon atom readily rearranged themselves into aldehydes or ketones, and were only known in their derivatives, especially as *ethers*. Thus:

1. *Vinyl Ether*, $(CH_2{=}CH)_2O$, b.p. 39°, may be obtained from vinyl sulphide (p. 143) and silver oxide. 2. *Perchlorovinyl Ether, Chloroxethose* $(CCl_2{=}CCl)_2O$, is formed from perchlorethyl ether (above) and K_2S. 3. *Vinyl Ethyl Ether*, b.p. 35·5°, results from the interaction of iodoethyl ether and sodium ethoxide; also from acetal by P_2O_5 and quinoline (B. **31**, 1021). 4. *Isopropenyl Ethyl Ether*, $CH_3C(OC_2H_5){=}CH_2$, b.p. 62–63°, is formed from propenyl bromide and alcoholic potassium hydroxide, and from ethoxycrotonic acid (B. **29**, 1005). Also, the homologues of β-alkoxyacrylic acid easily part with CO_2 and yield the homologues of *alkoxyethylene ether*, $RC.(OC_2H_5):CHR'$; they all yield ketones and alcoho when hydrolized with dilute acids (C. 1904, I. 719; B. **39**, 1410 footnote).

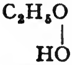
Ethers of allyl alcohol and propargyl alcohol are known: *Allyl Ether*, $(CH_2{=}CH.CH_2)_2O$, b.p. 85°; *Propargyl Ethyl Ether*, $CH{\equiv}C.CH_2.O.CH_2.CH_3$, b.p. 80°. (See Ethyl Propiolic Ester.)

ALKYL HYDROGEN AND DIALKYL PEROXIDES

The alkyl hydrogen peroxides and the dialkyl peroxides stand in the same relation to hydrogen peroxide, as the monohydric alcohols and the ethers do to water:

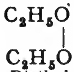
$$\begin{array}{c}HO\\|\\HO\end{array}$$

Hydrogen Peroxide.



$$\begin{array}{c}C_2H_5O\\|\\HO\end{array}$$

Ethyl Hydrogen Peroxide.



$$\begin{array}{c}C_2H_5O\\|\\C_2H_5O\end{array}$$

Diethyl Peroxide.

Since hydrogen peroxide behaves like a weak acid, the mono- and di-substituted compounds can be looked upon as the mono- and di-alkyl esters of the acid. Ethyl hydrogen peroxide and diethyl peroxide are the only members which have been closely studied. They result from the interaction of diethyl sulphate and a 12 per cent. solution of hydrogen peroxide, and the subsequent slow addition of potassium hydroxide solution during continuous shaking. An excess of hydrogen peroxide favours the production of ethyl hydrogen peroxide (*Baeyer* and *Villiger*, B. **34**, 738).

Ethyl Hydrogen Peroxide, $C_2H_5O.OH$, b.p.$_{100}$ 26–47°, is a colourless liquid, which can be distilled without decomposition, under reduced pressure. It is miscible with water, alcohol, and ether, and can be separated out from its aqueous solution by the addition of ammonium sulphate and potassium carbonate. Its odour is that of bleaching powder and acetaldehyde together. A drop of the concentrated solution on the skin causes inflammation. When rapidly heated, it detonates, and a strong explosion occurs when it is brought into contact with very finely divided silver. Acyl derivatives of hydrogen peroxide result from interaction with carboxylic anhydrides. Tertiary bases are oxidized to aminoxides.

Barium salt, $(C_2H_5OO)_2Ba+2H_2O$, is formed by dissolving barium hydroxide in an aqueous solution of ethyl hydrogen peroxide. It crystallizes as a leafy mass.

Diethyl Peroxide, $CH_3CH_2.O.O.CH_2CH_3$, b.p. 65°, $D_4^{15} = 0{\cdot}8273$. It is slightly soluble in water, but soluble in alcohol and ether. On contact with a thermometer heated to 250° it burns rapidly but without noise. If the liquid, in a CO_2 atmosphere, is approached by a heated copper wire which is then removed, it disappears very quickly without generation of light or boiling; this phenomenon is looked on as being a slow explosion. The products of combustion consist of formaldehyde and CO, together with some ethane.

2. ESTERS OF THE MINERAL ACIDS

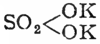
If we compare the alcohols with the metallic bases, the esters or compound ethers (p. 126) are perfectly analogous in constitution to the salts. Just as salts result from the union of metallic hydroxides with acids, so esters are formed by the combination of alcohols with acids, water being formed in both reactions:

$$NaOH+HCl = NaCl+H_2O.$$
$$C_2H_5OH+HCl=C_2H_5Cl+H_2O.$$

The haloid esters correspond to the haloid salts; they may also be regarded as monohalogen substitution products of the hydrocarbons (p. 193). Corresponding with the oxygen salts are the esters of other acids, which, therefore, may be viewed as derivatives of the alcohols, in which the *alcohol-hydrogen* has been replaced by acid radicals, or as derivatives of the acids, in which the hydrogen replaceable by metals has been substituted by alcohol radicals. The haloid esters would be included in the last definition of esters. The various definitions of esters as derivatives of the acids, and again as derivatives of the alcohols, find expression in the different designations of the esters:

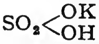
$C_2H_5.O.NO_2$	or	$NO_2.O.C_2H_5$.
Ethyl Nitrate.		Nitric Ethyl Ester.

In polybasic acids all the hydrogen atoms can be replaced by alcoholic radicals, whereby *neutral esters* are produced. When all the hydrogen atoms are not replaced by alcoholic radicals, *acid esters* are formed, which still possess the acid character. They form salts, hence are termed *ester acids*, and correspond with acid salts:



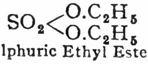
$SO_2<\begin{array}{l}OK\\OK\end{array}$

Neutral Potassium Sulphate



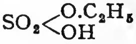
$SO_2<\begin{array}{l}OK\\OH\end{array}$

Acid Potassium Sulphate.



$SO_2<\begin{array}{l}O.C_2H_5\\O.C_2H_5\end{array}$

Sulphuric Ethyl Ester.



$SO_2<\begin{array}{l}O.C_2H_5\\OH\end{array}$

Ethyl Sulphuric Acid.

Dibasic acids form two series of salts, and also of esters, whilst with *tribasic acids* there are three series of salts and of esters.

In the case of the polyhydric alcohols there are, besides the neutral esters, also *basic esters*, corresponding with the basic salts, in which not all of the hydroxyl groups were esterified.

Formation of Esters.—(1) The esters can be prepared by direct combination of alcohols and acids, when water is also produced:

$$C_2H_5.OH+NO_2.OH=C_2H_5.O.NO_2+H_2O.$$

This reaction, however, only takes place gradually, progressing with time; it is accelerated by heat, but is never complete, free alcohol and acid remain uncombined together with the ester, and they do not react any further upon each other. If the *ester* be removed—*e.g.* by distillation—from the mixture, as it is formed, an almost perfect reaction may be attained.

When acted on by alcohols, the polybasic acids mostly yield the primary esters, the ester- or ether-acids.

There are two synthetic methods of producing the esters which favour the views of considering them derivatives of alcohols or acids. These are:

(2) By reacting on the acids (their silver or alkali salts) with alkylogens:

$$NO_2.O.Ag+C_2H_5I=NO_2.O.C_2H_5+AgI.$$

(3) By acting on the alcohols or metallic alcoholates with acid chlorides:

$$2C_2H_5.OH+SO_2Cl_2=SO_2{<}\begin{matrix}O.C_2H_5\\O.C_2H_5\end{matrix}+2HCl.$$

$$3C_2H_5.OH + BCl_3=B(O.C_2H_5)_3 + 3HCl.$$

Properties.—The neutral esters are insoluble, or soluble with difficulty in water, and almost all are volatile; therefore the determination of their vapour density is a convenient means of establishing the molecular magnitude and also the basicity of the acids. The ester acids are not volatile, but are soluble in water and yield salts with the bases.

All esters, and especially the ester-acids, are decomposed into alcohols and acids (p. 104) when heated with water. Sodium and potassium hydroxides, in aqueous or alcoholic solution, accomplish this with great readiness when heated. This process is termed *saponification*, because the *soaps*—*i.e.* the potassium and sodium salts of the higher fatty acids (*q.v.*)—are obtained by this reaction from the fats, the glycerol esters:

$$NO_2.O.C_2H_5+KOH=C_2H_5OH+NO_2OK.$$

A more general term is *hydrolysis*; both words, unfortunately, have become almost equivalent.—(Tr.)

A. I. ALKYL ESTERS OF THE HALOGEN ACIDS, HALOGEN ESTERS OF THE SATURATED ALCOHOLS, HALOGEN ALKYLS

It was pointed out under the halogen substitution products of the paraffins and the unsaturated acyclic hydrocarbons that the *mono-halogen* substitution products, or *alkylogens*, were mostly prepared from the alcohols. This intimate connection with the alcohols is the reason for the assumption of the alkylogens as esters of the haloid acids. As haloid esters of the alcohols they range themselves with the alkyl esters of the inorganic oxygen acids.

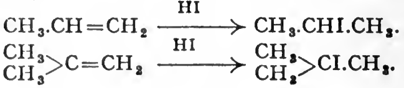
The view that the halogen derivatives $C_nH_{2n+1}X$ are paraffin substitution products is expressed in the names monochloro-methane, monochloro-ethane, etc., whilst the designation methyl chloride, ethyl chloride, etc., for the mono-halogen substitution derivatives of methane and ethane, mark these substances as haloid esters of the alcohols, corresponding with the metallic halides. The former mode of expression is, however, preferable, and will in the main be adopted here except in certain cases for definite reasons, because there is little in the properties of, say, methyl chloride to connect it with the chlorides as usually understood.

Formation of Alkylogens.—(1) *By the substitution of the paraffins.* The conditions favouring the substitution of the hydrogen atoms of the paraffins by halogen atoms have been mentioned under the general methods for the preparation of halogen substitution products. The substitution reaction is not well adapted for the preparation of alkylogens, because mixtures of compounds are invariably produced, and among the higher members of the series isomers are formed. This is because the chlorine replaces the hydrogen both of terminal and intermediate carbon atoms (B. **39**, 2153). Thus normal pentane,

$$\begin{aligned} CH_3.CH_2.CH_2.CH_2.CH_3 \text{ yields } & CH_3.CH_2.CHCl.CH_2.CH_3 \text{ and} \\ & CH_3.CH_2.CH_2.CHCl.CH_3, \\ & CH_3CH_2CH_2CH_2CH_2Cl, \end{aligned}$$

and such mixtures are separated with great difficulty.

(2) *By the addition of halogen acids to the olefines.*—In this addition, which occurs with especial ease with hydriodic acid, it is interesting to note that the halogen atom attaches itself to the carbon atom carrying the least number of hydrogen atoms (p. 184):



$$CH_3.CH{=}CH_2 \xrightarrow{HI} CH_3.CHI.CH_3.$$
$$\begin{matrix}CH_3\\CH_3\end{matrix}{>}C{=}CH_2 \xrightarrow{HI} \begin{matrix}CH_3\\CH_3\end{matrix}{>}CI.CH_3.$$

In the case of propylene and hydriodic acid, some iodo-n-propane is also formed (*Michael*, B. **39**, 2138).

(3) *From alcohols* (*a*) *by the action of halogen acids.*—This reaction is not complete unless the halogen acid is used in great excess, or the water formed at the same time with the alkylogen is absorbed. Hence in the case of methyl and ethyl alcohol an addition of zinc chloride or sulphuric acid is advantageous (see mono chloro methane, p. 135). Tertiary alcohols are specially easily converted into chlorides by hydrochloric acid.

This addition is a disadvantage in the case of the higher alcohols, because olefines are first produced, and to these the halogen acid becomes added in such a manner that an isomer of the desired alkylogen is obtained (p. 84). Hence alkyl iodides can be prepared from polyhydric alcohols (comp. Isopropyl Iodide, p. 136):

$$\begin{aligned} C_2H_4(OH)_2 + 3HI &= C_2H_5I + I_2 + 2H_2O. \\ C_3H_5(OH)_3 + 5HI &= C_3H_7I + 2I_2 + 3H_2O. \\ C_4H_6(OH)_4 + 7HI &= C_4H_9I + 3I_2 + 4H_2O. \\ C_6H_8(OH)_6 + 11HI &= C_6H_{13}I + 5I_2 + 6H_2O. \end{aligned}$$

It may also be remarked that in the presence of an excess of hydriodic acid the iodides are often reduced.

(*b*) *By the action of phosphorus halides.*—If, for example, ethyl alcohol be treated with PCl_3, PBr_3, or PI_3, two possibilities arise: either a halogen acid and ethyl phosphorous ester are produced, or an ethyl halide and phosphorous acid. The latter reaction occurs when PBr_3 and PI_3 are used, and this method is adopted almost exclusively in the preparation of the alkyl bromides and iodides (see ethyl bromide and ethyl iodide):

$$PBr_3+3C_2H_5OH=3C_2H_5Br+H_3PO_3.$$
$$PI_3+3C_2H_5OH=3C_2H_5I+H_3PO_3.$$

(BI_3 acts analogously on ethyl alcohol, B. **24**, R. 387.) The formation of esters of phosphorous acid by the use of PBr_3 and PI_3 is far from satisfactory. PCl_3, on the other hand, yields phosphorous esters and hydrochloric acid almost entirely according to the equation (C. 1905, II. 1664; see p. 141):

$$PCl_3+3C_2H_5OH=P(OC_2H_5)_3+3HCl.$$

The chlorides are readily formed if PCl_5 be substituted for PCl_3:

$$PCl_5+C_2H_5OH=C_2H_5Cl+HCl+POCl_3.$$

(4) *From alkyl halides or alkyl sulphuric acids and metallic halides.*

(*a*) Bromides and iodides can be transformed into chlorides by heating them with $HgCl_2$:

$$2C_3H_7I+HgCl_2=2C_3H_7Cl+HgI_2.$$

(*b*) When chlorides are heated with $AlBr_3$ or AlI_3 or CaI_2 they become converted into bromides or iodides (B. **14**, 1709; **16**, 392; **19**, R. 166):

$$3C_2H_5Cl+AlBr_3=3C_2H_5Br+AlCl_3.$$

(*c*) Methyl and ethyl iodides yield with AgF the gaseous compounds *methyl fluoride*, CH_3F, and *ethyl fluoride*, C_2H_5F, which have an agreeable, ethereal odour, and do not attack glass (B. **22**, R. 267).

(*d*) On distilling ethyl sulphuric acid and potassium bromide, ethyl bromide is produced. Methyl and ethyl sulphates with alkali iodides in aqueous solution yield methyl and ethyl iodides.

(*e*) Magnesium alkyl chlorides or bromides yield iodo-alkyls with iodine (C. 1903, I. 318):

$$C_5H_{11}MgCl+I_2=C_5H_{11}I+MgCl.$$

Isomerism.—Propane is the first hydrocarbon capable of yielding isomers (p. 27). The isomerism depends on the varying position of the hydrogen atoms in the same carbon chain, and from butane forward it depends on the different linkage of the carbon atoms forming the carbon skeleton (see table, p. 134).

Properties and Reactions.—The alkylogens are ethereal, agreeable, sweet-smelling liquids. They are scarcely soluble in water, but dissolve with ease in alcohol and ether. They are gases at the ordinary temperature—*e.g.* methyl chloride, ethyl chloride, and methyl bromide. The chlorides boil 28–20° lower than the bromides, and the latter from 34–28° lower than the corresponding iodides (p. 134). The differences grow less with increasing molecular weight. As in the case of the paraffins, here also, where isomers exist, the normal members have the highest boiling points; the more branched the carbon chain, the lower will the boiling point lie.

As *halogen esters* of the alcohols, the alkylogens may be compared with the metallic halides, although the halogens are less readily transposed by silver nitrate. The iodides are the most reactive. However, the alkylogens are excellently adapted to bring about the replacement of metals, and thus to unite alcohol radicals and atoms which previously were combined with metals. Particularly interesting is the reaction between the alkaline cyanides (see nitriles), and the sodium derivatives of acetoacetic ester (*q.v.*) and malonic ester (*q.v.*). Both are *synthetic reactions* of the first importance (p. 75). The alkylogens play a prominent part in the *nucleus-syntheses* of the paraffins (see Ethane, p. 72). They constitute the transition from the paraffins and olefines to the alcohols, into which they are converted, for example, by moist silver oxide.

The methods for the conversion of alcohols into ethers, into mercaptans (sulphur-alcohols), into alkyl sulphides (sulphur-ethers) and compound mineral ethers or esters, are based upon the reactivity of the halogen atoms in the alkylogens. This is also the case with the methods employed in the preparation of metal alkyls, especially zinc alkyls and magnesium alkylogens.

Among the numerous reactions of the alkylogens, mention may here be made of their power to unite with ammonia and ammonium bases. By this means the primary, secondary, and tertiary amines, as well as the tetra-alkyl ammonium halides, were obtained.

The following table contains the boiling points of some of the alkylogens at the ordinary pressure :—

Name and Formula of Radical.		Chloride.	Bromide.	Iodide.
Methyl-	CH_3—	−24°	+4·5°	43°
Ethyl-	CH_3CH_2—	+12·5°	38°	72°
n-Propyl-	$CH_3CH_2CH_2$—	44°	71°	102°
Isopropyl-	$(CH_3)_2CH$—	36·5°	59·5°	89·5°
n-Butyl-	$CH_3CH_2CH_2CH_2$—	77·5°	100·4°	129·6°
Isobutyl-	$(CH_3)_2CHCH_2$—	68·5°	92°	120°
sec.-Butyl-	$\begin{matrix}CH_3\\C_2H_5\end{matrix}>CH$—	. . .	. . .	120°
tert.-Butyl-	$(CH_3)_3C$—	51·5°	72°	103·3°
n-Amyl-	$CH_3.[CH_2]_3CH_2$—	106°	129°	155°
Isoamyl-	$(CH_3)_2CH.CH_2.CH_2$—	100°	120°	148°
Diethyl Methyl-	$(C_2H_5)_2CH$—	. . .	. . .	145°
Methyl n-Propyl Methyl .	$\begin{matrix}CH_3\\CH_3CH_2CH_2\end{matrix}>CH$—	104°	113°	144°
Methyl Isopropyl Methyl-	$\begin{matrix}CH_3\\(CH_3)_2CH\end{matrix}>CH$—	91°	115°	138°
Dimethyl Ethyl Methyl- .	$\begin{matrix}(CH_3)_2\\C_2H_5\end{matrix}>C$—	86°	100°	127°
n-Hexyl-	$CH_3[CH_2]_4CH_2$—	133°	155°	179°
n-Heptyl-	$CH_3[CH_2]_5CH_2$—	159°	178°	203°
n-Octyl-	$CH_3[CH_2]_6CH_2$—	180°	199°	225°

Monofluoromethane CH_3F, b.p. −78°, is formed according to mode of preparation (4) (*c*) (p. 133), and by heating tetramethyl ammonium fluoride (C. 1904, II. 1281).

Monochloromethane, Methyl Chloride, CH_3Cl, m.p. —103° (B. **33**, 638), is obtained from methane or methyl alcohol. It is a sweet-smelling gas. Alcohol will dissolve 35 volumes of it, and water 4 volumes.

It is prepared by heating a mixture of 1 part methyl alcohol (wood spirit), 2 parts sodium chloride, and 3 parts sulphuric acid. A better plan is to conduct HCl into boiling methyl alcohol in the presence of zinc chloride ($\frac{1}{2}$ part). The disengaged gas is washed with KOH, and dried by means of sulphuric acid. Commercial methyl chloride is obtained by heating trimethylamine hydrochloride, $N(CH_3)_3.HCl$, and is usually supplied in a compressed condition. It was formerly employed in the manufacture of the aniline dyes, and in producing cold.

Monochlorethane, Ethyl Chloride, C_2H_5Cl, b.p. 12·5°, $D_0 = 0·921$. It is prepared from ethyl alcohol in the same manner that methyl chloride is obtained from its alcohol. Its formation from "ethyl hydride" or dimethyl by means of chlorine (p. 72) is important from a theoretical standpoint.

It is an ethereal liquid, miscible with alcohol, and but sparingly soluble in water.

If heated with water at 100° in a sealed tube, it changes to ethyl alcohol, a conversion which is accelerated by potassium hydroxide. In diffused sunlight, chlorine acts upon it to form ethylidene chloride, $CH_3.CHCl_2$, and other substitution products. Of these C_2HCl_5 was formerly employed as *Æther anæstheticus.* Chlorine, in the presence of iron, converts chlorethane into ethylene chloride.

Myricyl chloride, $CH_3[CH_2]_{28}CH_2Cl$, m.p. 64°.

Methyl Bromide, Monobromomethane, CH_3Br, D_0 1·73 (B. **38**, 1865).

Monobromethane, Ethyl Bromide, C_2H_5Br, b.p. 39°; $D_{13} = 1·47$. It is prepared from potassium bromide and ethyl sulphuric acid (p. 126). It is used as a narcotic, and is known as the officinal *Æther bromatus.*

Bromopropane, Propyl Bromide, C_3H_7Br, b.p. 71°; $D_{20} = 1·3520$, is prepared from the normal alcohol (C. 1906, II. 1042).

Bromo-isopropane, Isopropyl Bromide, C_3H_7Br, b.p. 59·50°; $D_{20} = 1·3097$, is obtained from its corresponding alcohol. It is most conveniently prepared by the action of bromine on isopropyl iodide (B. **15**, 1904). On boiling with aluminium bromide, or by heating to 250°, normal bromopropane is partially converted into the bromo-isopropane (B. **16**, 391). It may be assumed that the normal bromopropane, $CH_3.CH_2.CH_2.Br$, at first breaks up into propylene, $CH_3.CH{:}CH_2$ and HBr, which then, according to a common rule of addition (p. 84), unites with the propylene to bromo-isopropane, $CH_3.CHBr.CH_3$. Similarly, the bromo-isobutane $(CH_3)_2.CH.CH_2.Br$, changes at 240° to tert.-bromobutane, $(CH_3)_2.CBr.CH_3$. The reactions occurring on heating the halogen acids with the alcohols may be explained in the same manner.

The table already referred to also contains the boiling points of some of the higher homologues.

Cetyl Bromide, $CH_3[CH_2]_{14}CH_2Br$, m.p. 15°.

On exposure to the air the iodides soon become discoloured by deposition of iodine. The iodides of the secondary and tertiary alcohols are easily converted by heat into alkylenes, C_nH_{2n}, and HI. Consult A. **243,** 30, upon the specific volumes of the iodo-alkyls.

Iodomethane Methyl Iodide, CH_3I, b.p. 43°; $D_0 = 2{\cdot}19$, is prepared from methyl alcohol, iodine, and phosphorus, or from dimethyl sulphate and potassium iodide in aqueous solution (C. 1906, II. 1589). It is a heavy, sweet-smelling liquid, and unites with H_2O to form a crystalline hydrate, $2CH_3I+H_2O$, and with methyl alcohol to form a compound, $3CH_3I+CH_3OH$, b.p. 40°, without decomposition (C. 1901, II. 179). At low temperatures the iodo-alkyls take up chlorine, forming extremely easily decomposable iodo chlorides:

Methyl Iodochloride, CH_3Cl_2, m.p. −28°, consists of yellow crystals. It decomposes into iodine chloride and chloromethane (B. **38,** 2842).

Iodoethane, Ethyl Iodide, C_2H_5I, m.p. −113°, $D_0 = 1{\cdot}975$, was discovered by *Gay-Lussac* in 1815. It is prepared from alcohol, iodine and phosphorus; or from diethyl sulphate with potassium iodide solution (C. 1906, II. 1589). It is a colourless, strongly refracting liquid.

Propyl Iodide, C_3H_7I, b.p. 102°, D_{20} 1·7427, from propyl alcohol.

Iodoisopropane, Isopropyl Iodide, C_3H_7I, b.p. 89·5°, $D_{20} = 1{\cdot}7033$, is prepared from isopropyl alcohol, propylene glycol, $C_3H_6(OH)_2$, or from propylene, and, most conveniently, by distilling a mixture of glycerol, amorphous phosphorus, and iodine (A. **138,** 364):

$$C_3H_5(OH)_3+5HI=C_3H_7I+2I_2+3H_2O.$$

Here allyl iodide, $CH_2{=}CH{-}CH_2I$, is first produced (see below), which is further changed to propylene, $CH_2{=}CH{-}CH_3$, and isopropyl iodide.

The boiling points of some of the higher alkylogens will be found in the preceding table. *Cetyl Iodide,* $CH_3{\cdot}[CH_2]_{14}CH_2I$, m.p. 22°, and *Myricyl Iodide,* $CH_3[CH_2]_{28}CH_2I$, m.p. 70°.

II. HALOGEN ESTERS OF THE UNSATURATED ALCOHOLS

Only the halogen esters of the most important olefine and acetylene alcohols will be given; they are the **allyl halides** and the **propargyl halides.** The former are prepared from allyl alcohol by methods similar to those employed for the preparation of the corresponding compounds from ethyl alcohol. They are isomeric with the β- and α-haloid propylenes (p. 97), from which they are distinguished by their adaptability for double decompositions:

	Formula.	Boiling Point.	Sp. Gravity.
Allyl Fluoride (B. **24**, R. 40)	$CH_2{=}CH.CH_2F$	−10°	. . .
Allyl Chloride	$CH_2{=}CH.CH_2Cl$	46°	0·9379 (20°)
Allyl Bromide	$CH_2{=}CH.CH_2Br$	71°	1·461 (0°)
Allyl Iodide	$CH_2{=}CH.CH_2I$	101°	1·789 (16°)

The allyl halides are liquids with leek-like odour. Allyl chloride, heated to 100° with HCl, yields propylene chloride, $CH_2CHCl.CH_2Cl$. Allyl bromide, heated to 100° with HBr passes into trimethylene bromide, $CH_2Br.CH_2.CH_2Br$. The addition of halogens produces glycerol trihaloid esters.

Allyl Iodide. It is readily prepared from glycerol by the action of HI, or iodine and phosphorus. It may be supposed that at first $CH_2I.CHI.CH_2I$ forms, but is subsequently decomposed into allyl iodide and iodine. (Preparation: A. **185,** 191; **226,** 206.) With excess of HI or phosphorus iodide, allyl iodide is further converted into propylene and isopropyl iodide (see above).

By continued shaking of allyl iodide in alcoholic solution with mercury, C_3H_5HgI separates in colourless leaflets (see mercury ethyl). Iodine liberates pure allyl iodide from this:

$$C_3H_5HgI+I_2=C_3H_5I+HgI_2.$$

Alcoholic potassium hydroxide converts allyl iodide into allyl ethyl ether. With potassium sulphide it yields *allyl sulphide* (p. 144); with potassium thiocyanate, *allyl thiocyanate,* which passes readily into allyl mustard oil (*q.v.*). Allyl iodide has also been used in the synthesis of unsaturated alcohols.

Name.	Formula.	Boiling Point	Sp. Gravity.
Propargyl Chloride (B. **8,** 398) .	$CH\equiv C.CH_2Cl$	65°	1·0454 (5°)
Propargyl Bromide (B. **7,** 761) .	$CH\equiv C.CH_2Br$	89°	1·5200 (20°)
Propargyl Iodide (B. **17,** 1132) .	$CH\equiv C.CH_2I$	115°	2·0177 (0°)

Propargyl chloride is produced when phosphorus trichloride acts on propargyl alcohol.

B. ESTERS OF NITRIC ACID

They are prepared by the interaction of alcohols and nitric acid (C. 1903, II. 338). Nitrous acid is always produced, as a consequence of secondary reactions oxidizing and may be destroyed by the addition of urea:

$$CO(NH_2)_2+2HNO_2=CO_2+2N_2+3H_2O.$$

When much nitrous acid is present, it induces the decomposition of the nitric acid ester, and causes explosions.

Methyl Nitric Ester, *Methyl Nitrate,* b.p. 60°; $D_{20}=1{\cdot}182$. When struck or heated to 150° it explodes very violently.

Ethyl Nitric Ester, *Ethyl Nitrate,* $C_2H_5.O.NO_2$, b.p. 86°; $D_{15}=1{\cdot}112$, is a colourless, pleasant-smelling liquid. It is almost insoluble in water, and burns with a white light. It will explode if suddenly exposed to a high temperature. Heated with ammonia, it passes into ethylamine nitrate. Tin and hydrochloric acid convert it into hydroxylamine.

Propyl Nitrate, $C_3H_7O.NO_2$ (B. **14,** 421), b.p. 110°; *Isopropyl Nitrate,* b.p. 101–102°; *Isobutyl Nitrate,* b.p. 123°; *Isoamyl Nitrate,* b.p. 148°; *n-Octyl Nitrate,* b.p.$_{20}$ 110°; *Myristyl Nitrate,* b.p.$_{12}$ 175–180°.

C. ESTERS OF NITROUS ACID

These are isomeric with the nitro-paraffins. The group NO_2 is present in both; whilst, however, in the nitro-compounds nitrogen is combined with carbon, in the esters the union is effected by oxygen:

$C_2H_5.NO_2$
Nitro-ethane.

$C_2H_5.O.NO.$
Ethyl Nitrous Ester.

The nitrous esters, as might be inferred from their different structure, decompose into alcohols and nitrous acid when acted on by alkalis. Similar treatment will not decompose the nitro-compounds. Nascent hydrogen (tin and hydrochloric acid) converts the latter into amines, whilst the esters are hydrolized.

Nitrous acid esters are produced in (1) the action of nitrous acid on the alcohols in dilute aqueous solution (B. **34,** 755); (2) by the action of iodo-alkyls on silver nitrite (B. **25,** R. 571) together with nitro-paraffins of much higher boiling points; (3) by the introduction of nitrosyl chloride into a pyridine solution of the alcohol (C. 1903, II. 339).

Methyl Nitrous Ester, *Methyl Nitrite,* $CH_3.O.NO$, b.p. −12°.

Ethyl Nitrous Ester, *Ethyl Nitrite,* $C_2H_5.O.NO$, b.p. 16°, $D_{15} = 0{\cdot}947$, is obtained by the action of sulphuric acid and potassium nitrite on alcohol (A. **253,** 251, footnote). It is a mobile, yellowish liquid. It is insoluble in water, and possesses an odour resembling that of apples. It is the active ingredient of *Spiritus ætheris nitrosi.*

When ethyl nitrite stands in contact with water it gradually decomposes, nitrogen oxide being evolved; an explosion may occur under some conditions. Hydrogen sulphide changes it into alcohol and ammonia.

n-Butyl Nitrite, $C_4H_9.O.NO$, b.p. 75°, **sec.-Butyl Nitrite,** b.p. 68°, **tert.-Butyl Nitrite,** b.p. 77°, **n-Octyl Nitrite,** b.p. 175° (C. 1903, II. 339).

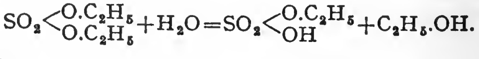
Isoamyl Nitrous Ester, $C_5H_{11}O.NO$, b.p. 96°; $D = 0{\cdot}902$, is obtained by passing nitrous vapours into amyl alcohol at 100°. It is a yellow liquid. An explosion takes place when the vapours are heated to 250°. Nascent hydrogen changes it into amyl alcohol and ammonia. Heated with methyl alcohol, it is transformed into methyl nitrite and amyl alcohol; ethyl alcohol behaves analogously (B. **20,** 656).

Amyl nitrite, "*Amylium nitrosum,*" is used in medicine, and also for the preparation of nitroso- and diazo-compounds.

NOTE.—*Diazoethoxane,* $C_2H_5O-N=N-OC_2H_5$, results from the interaction of iodoethane and nitrosyl silver $(NOAg)_2$. It is the ester of hyponitrous acid (B. **11,** 1630).

D. ESTERS OF SULPHURIC ACID

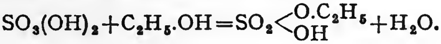
1. The *normal,* or *dialkyl esters* are prepared (1) by the interaction of iodo-alkyls and silver sulphate; (2) from chlorosulphonic esters or sulphuryl chloride and sodium alcoholate, together with by-products (C. 1903, II. 936). They result (3), in small quantities, by heating mono-ethyl sulphuric ester alone, or the alcohol with sulphuric acid, and can be extracted from the reaction products by chloroform. A better method is to pass methyl ether into H_2SO_4 at 160° (C. 1901, II. 269). Fuming sulphuric acid at ordinary temperatures yields mainly neutral esters with methyl and ethyl alcohols (C. 1900, II. 614). They are heavy liquids, soluble in ether, possess an odour like that of peppermint, and boil without decomposition. They will sink in water, and gradually decompose into a primary ester and alcohol:



$$SO_2{<}^{O.C_2H_5}_{O.C_2H_5} + H_2O = SO_2{<}^{O.C_2H_5}_{OH} + C_2H_5.OH.$$

Dimethyl Ester, *Dimethyl Sulphate,* $SO_2(OCH_3)_2$, b.p. 188°, is conveniently prepared by the interaction of methyl alcohol and chlorosulphonic acid. It is highly irritating to the mucous membrane (C. 1901, I. 265), and is poisonous (C. 1902, I. 364). It is frequently employed in the preparation of methyl ethers, esters, and amines (A. **327,** 104). *Diethyl Ester, Diethyl Sulphate,* $SO_2(OC_2H_5)_2$, b.p. 208°, may also be prepared from SO_3 and $(C_2H_5)_2O$. Heated with alcohol it forms ethyl sulphuric acid and ethyl ether (B. **13**, 1699; **15**, 947); it is an excellent reagent for alkylation (B. **33**, 2476) (comp. Ethyl Hydrogen Peroxide, p. 129). *Di-isobutyl Ester*, b.p.$_{18}$ 134°, and *Di-isoamyl Ester*, b.p.$_{12}$ 150°, are prepared from the respective sodium carboxylates and SO_2Cl_2 (C. 1903, II. 937).

2. The primary esters or **ether-acids** are produced (1) when the alcohols are mixed with concentrated sulphuric acid:



$$SO_2(OH)_2+C_2H_5.OH=SO_2{<}^{O.C_2H_5}_{OH}+H_2O.$$

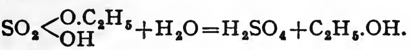
The reaction takes place only when aided by heat, and it is not complete. The reaction proceeds to completion if the alcohol be dissolved in very little sulphuric acid, and SO_3 in the form of fuming sulphuric acid be then allowed to act on the well-cooled solution (B. **28**, R. 31). To isolate the ether-acids, the product of the reaction is diluted with water and boiled with an excess of barium carbonate. In this way the unaffected sulphuric acid is thrown out as barium sulphate; the barium salts of the ether-acids are soluble and crystallize out when the solution is evaporated. To obtain the acids in a free state their salts are treated with sulphuric acid or the lead salts (obtained by saturating the acids with lead carbonate) may be decomposed by hydrogen sulphide, and the solution allowed to evaporate over sulphuric acid.

Secondary alcohols, also, by careful cooling of the reacting bodies, are capable of forming ether sulphuric acids—*e.g.* ethyl propyl carbinol (B. **26**, 1203); tertiary alcohols behave similarly (C. 1897, II. 408).

(2) The *ether-acids* also result from the union of the alkylenes with concentrated sulphuric acid.

Properties.—These esters are thick liquids, which cannot be distilled, but which sometimes crystallize. They dissolve readily in water and alcohol, but are insoluble in ether.

(1) When boiled or warmed with water they break down into sulphuric acid and alcohol:



$$SO_2{<}^{O.C_2H_5}_{OH}+H_2O=H_2SO_4+C_2H_5.OH.$$

(2) When distilled, they yield sulphuric acid and alkylenes (p. 83).

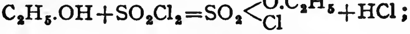
(3) When heated with alcohols, simple and mixed ethers (p. 126) are produced.

They show a strongly acid reaction, and furnish salts which dissolve quite readily in water, most of them crystallize readily. The salts gradually change to sulphates and alcohol when they are boiled with water. The alkali salts are frequently applied in different reactions. Thus with KSH and K_2S they yield mercaptans and thioethers (p. 143); with salts of fatty acids they furnish esters, and with KCN the alkyl cyanides, etc.

Methyl Sulphuric Acid, $SO_4(CH_3)H$, is a thick oil.

Ethyl Sulphuric Acid, $SO_4(C_2H_5)H$, is obtained by mixing 1 part alcohol with 2 parts concentrated sulphuric acid, and forms the basis of the *Mixt. sulf. acida* (Ph.G.): *potassium salt*, $SO_4(C_2H_5)K$, is anhydrous, and crystallizes in plates: *barium* and *calcium* salts crystallize in large tablets with two molecules of H_2O each (A. **218**, 300).

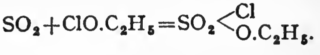
The *chlorides* or *chloranhydrides* of the ether sulphuric acids $\left(SO_2{<}^{O.C_2H_5}_{Cl}\right)$, called chlorosulphonic esters, result (1) by the action of sulphuryl chloride on the alcohols (C. 1903, II. 936; 1905, I. 14):



$$C_2H_5.OH+SO_2Cl_2=SO_2{<}^{O.C_2H_5}_{Cl}+HCl;$$

Chloride of Ethyl Sulphuric Acid.

(2) by the action of PCl_5 on salts of the ether acids; (3) by the union of the olefines with $Cl.SO_3H$; (4) by the union of SO_3 with the chloro-alkyls; and (5) by the action of SO_2 on the esters of hypochlorous acid (B. **19**, 860):



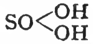
$$SO_2+ClO.C_2H_5=SO_2\begin{matrix}<\end{matrix}\begin{matrix}Cl\\O.C_2H_5.\end{matrix}$$

They are liquids possessing a penetrating odour. Cold water decomposes them slowly into the alkyl sulphuric acids. The same result accompanied by a violent evolution of chlorethane is brought about by alcohol. Sodium alcoholates of chlorosulphonic esters unite to form compounds which break down, giving rise to normal sulphonic ester, ether, sodium alkyl sulphate, and sodium sulphate. Aniline and phenols (Vol. II.) are alkylized by chlorosulphonic ester; sodium malonic ester and sodium acetic ester are chlorinated (C. 1905, I. 13).

Chloride of Ethyl Sulphuric Acid, $C_2H_5.O.SO_2Cl$, b.p.$_{14}$ 52°; $D_{18}=1{\cdot}263$. *Methyl Sulphuric Chloride,* $CH_3.O.SO_2Cl$, b.p. 132°.

E. ESTERS OF SULPHUROUS ACID

The empirical formula of sulphurous acid, H_2SO_3, may have two possible structures:



$$SO\begin{matrix}<\end{matrix}\begin{matrix}OH\\OH\end{matrix} \qquad \text{or} \qquad HSO_2.OH.$$

sym.-Sulphurous Acid. unsym.-Sulphurous Acid.

The ordinary sulphites correspond with formula 2, and it appears that in them one atom of metal is in direct combination with sulphur:

$Ag.SO_2.OAg$ Silver Sulphite. $K.SO_2.OH.$ Prim. Potassium Sulphite.

Silver sulphite, $AgSO_2.OAg$, when acted on by iodoethane, yields the ethyl ester of ethyl sulphuric acid, $C_2H_5.SO_3.C_2H_5$, which loses an ethyl group when treated with potassium hydroxide, and yields ethyl sulphuric acid, $C_2H_5.SO_3H$, the oxidation product of ethyl mercaptan, C_2H_5SH. The *sulpho-acids* and their esters, which must be viewed as esters of unsymmetrical sulphurous acid, will be described after the *mercaptans.*

The esters of symmetrical and unsymmetrical sulphurous acid are closely connected, as the following shows.

If SO_2 is passed into a solution of sodium or potassium alcoholate, or SO_2 and NH_3 into absolute alcohol, there are obtained unstable salts of alkyl sulphurous acid—$CH_3O.SO_2Na$, $C_2H_5O.SO_2K$, $C_3H_7O.SO_2Na$, $C_2H_5O.SO_2NH_3$, which easily lose SO_2 (B. **38**, 1298; C. 1902, II. 930). These salts are isomeric with the very stable alkyl sulphonic acid esters (p. 146). If sodium ethyl *sulphite* is heated with iodoethane or sodium iodide in alcoholic solution, it is converted into the double salt of sodium ethyl *sulphonate* with sodium iodide.

The dialkyl esters of symmetrical sulphurous acid are prepared by the action of thionyl chloride $SOCl_2$ or sulphur chloride on the alcohols:

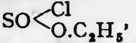
$$SOCl_2+2C_2H_5OH=SO(OC_2H_5)_2+2HCl.$$
$$S_2Cl_2+3C_2H_5OH=SO(OC_2H_5)+C_2H_5SH+2HCl.$$

The mercaptan which is formed undergoes further change.

The dialkyl sulphites are liquids, insoluble in water, having an odour of peppermint. They are isomeric with the corresponding esters of the alkyl sulphonic acids. It is remarkable that aqueous solutions of alkali hydroxides only hydrolyze the sulphites with difficulty, whilst the prolonged action of a cold concentrated solution partially converts them into alkyl sulphonic acids; a change which is also brought about by potassium iodide (see above) (B. **38**, 1298).

Dimethyl Sulphurous Ester, $SO(O.CH_3)_2$, *Dimethyl Sulphite,* b.p. 121°.

Diethyl Sulphite, $SO(O.C_2H_5)_2$, b.p. 161°, $D_0 = 1{\cdot}106$, is converted by PCl_5 into the *chloride*, $SO\!<\!\begin{matrix}Cl\\O.C_2H_5\end{matrix}$, b.p. 122°, which is easily decomposed by water into alcohol, SO_2 and HCl. It is isomeric with ethyl sulphonic chloride (p. 147), *Dipropyl Sulphite*, b.p. 191°.



F. ESTERS OF HYPOCHLOROUS AND PERCHLORIC ACIDS

The **Esters** of hypochlorous acid, HClO, are formed by mixing the free acid with alcohols. They are pungently-smelling, explosive liquids (B. **18**, 1767; **19**, 857), from which the explosive esters of perchloric acid are obtained by the action of iodo-alkyls on the silver salt.

Methyl Hypochlorite, b.p. 12°; **Ethyl Hypochlorite**, b.p. 36°.

On the behaviour of alkyl hypochlorates and SO_2, see p. 140; and with KCN, see chlorimidocarbonic ester.

G. ESTERS OF BORIC ACID, ORTHO-PHOSPHORIC ACID, SYM.-PHOSPHOROUS ACID, ARSENIC ACID, SYM.-ARSENIOUS ACID, AND THE SILICIC ACIDS

These esters are obtained by the action of BCl_3, B_2O_3, $POCl_3$, PCl_3, $AsBr_3$, $SiCl_4$, Si_2OCl_6 on alcohols and sodium alcoholates. Alkali hydroxides hydrolyze them with the production of alcohols and alkali salts of the respective inorganic acids. Most of them are decomposed entirely or in part by water.

Methyl Borate, $B(OCH_3)_3$, b.p. 65°, and

Ethyl Borate, $B(OC_2H_5)_3$, b.p. 119°, both burn with a green flame (C. 1898, II. 1243).

Ethyl Phosphate, $PO(OC_2H_5)_3$, b.p. 211° (C. 1900, I. 102).

sym.-*Methyl Phosphite*, $P(OCH_3)_3$, b.p. 111°, and

sym.-*Ethyl Phosphite*, $P(OC_2H_5)_3$, b.p. 156°, result from the action of PCl_3 on the corresponding sodium alcoholate solution. PCl_3 and alcohols yield mainly

Dialkyl esters of unsym.-*phosphorous acid*, $HPO(OR)_2$, which can also be obtained from the symmetrical trialkyl esters by the action of water or hydrochloric acid. The latter are isomerized by iodo-alkyls into *alkyl phospho-acid esters* (comp. p. 175) with the intermediate formation of addition products (comp. sulphurous acid esters):

$$HPO(OR)_2 \xleftarrow{H_2O} P(OR)_3 \xrightarrow{RI} RPO(OR)_2.$$

Cuprous halides also form addition compounds with the trialkyl phosphorous acid esters (C. 1903, II. 22; 1906, II. 1639; B. **38**, 1171).

Ethyl Arsenate, $AsO(OC_2H_5)_3$, b.p. 235°, is prepared from silver arsenate and iodoethane.

sym.-*Ethyl Arsenite*, $As(OC_2H_5)_3$, b.p. 166°.

For *Phospho-* and *Phosphinic acids* and the corresponding compounds of *arsenic*, comp. the *Phosphorus bases* and *Arsenic bases*.

Methyl Orthosilicate, $Si(OCH_3)_4$, b.p. 120-122°.

Ethyl Orthosilicate, $Si(OC_2H_5)_4$, b.p. 165°.

Ethyl Disilicate, $Si_2O(OC_2H_5)_6$, b.p. 236°.

Ethyl Metasilicate, $SiO(OC_2H_5)_2$, b.p. 360° (approximately).

The silicic esters burn with a brilliant white flame. The ortho- and metasilicic esters correspond with the o- and m- or ordinary carbonic acid esters: $C(OC_2H_5)_4$ and $CO(OC_2H_5)_2$.

The ortho formic esters $HC(OR)_3$ correspond with the o-silicoformic esters, $HSi(OR)_3$, which are produced from silicon chloroform, $SiHCl_3$ (see Inorganic Chemistry) and the alcohols. *Ethyl o-Silicoformate*, $HSi(OC_2H_5)_3$, b.p. 134°, *Propyl o-Silicoformate*, b.p. 192°, $D = 0{\cdot}885$. These esters yield silicon hydride when heated with sodium (B. **38**, 1661).

3. SULPHUR DERIVATIVES OF THE ALCOHOL RADICALS

The hydrosulphides and sulphides correspond with the metallic hydroxides and oxides, whilst the sulphur analogues of the alcohols and ethers are the *thio-alcohols, mercaptans*, or *alkyl hydrosulphides*, and *thio-ethers* or *alkyl-sulphides*, and the alkali polysulphides find their analogues in the *alkyl polysulphides* :

$$\begin{array}{ccccc}
\left.\begin{matrix}H\\H\end{matrix}\right\}O; & \left.\begin{matrix}Na\\H\end{matrix}\right\}O; & \left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O; & \left.\begin{matrix}Na\\Na\end{matrix}\right\}O; & \left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O \\
\left.\begin{matrix}H\\H\end{matrix}\right\}S; & \left.\begin{matrix}Na\\H\end{matrix}\right\}S; & \left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}S; & \left.\begin{matrix}Na\\Na\end{matrix}\right\}S; & \left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}S \\
 & & \text{Ethyl Hydrosulphide.} & & \text{Ethyl Sulphide.} \\
 & & & \left.\begin{matrix}Na\\Na\end{matrix}\right\}S_2; & \left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}S_2 \\
 & & & & \text{Ethyl Disulphide.}
\end{array}$$

A. **Mercaptans, Thio-alcohols,** or **Alkyl Hydrosulphides.**—Although the mercaptans closely resemble the alcohols in general, they are differentiated in that the hydrogen, which in the alcohols is replaceable by the alkali metals, is in the mercaptans also to be substituted by the heavy metals. The mercaptans react very readily with mercuric oxide, to form crystalline compounds:

$$2C_2H_5.SH + HgO = (C_2H_5.S)_2Hg + H_2O.$$

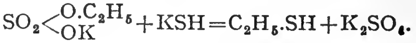
Hence their designation as mercaptans (from *mercurium captans*). The metal derivatives of the mercaptans are termed *mercaptides*.

Methods for their formation :

(1) By the action of the alkylogens on potassium hydrosulphide in alcoholic solution :

$$C_2H_5Cl + KSH = C_2H_5.SH + KCl.$$

(2) By distilling salts of the sulphuric esters with potassium hydrosulphide or potassium sulphide (see p. 139) :



$$SO_2{<}{\begin{matrix}O.C_2H_5\\OK\end{matrix}} + KSH = C_2H_5.SH + K_2SO_4.$$

The neutral esters of sulphuric acid—*e.g.* $SO_2(O.C_2H_5)_2$ (p. 139)—also yield mercaptans when heated with KSH.

(3) A direct replacement of the oxygen of alcohols and ethers by sulphur may be effected by phosphorous sulphide :

$$5C_2H_5OH + P_2S_5 = 5C_2H_5.SH + P_2O_5.$$

(4) By reduction of the chlorides of the sulphonic acids (*q.v.*) :

$$C_2H_5.SO_2Cl + 6H = C_2H_5SH + HCl + 2H_2O.$$

This reaction recalls the reduction of the acid chlorides to primary alcohols (p. 104).

Properties and Reactions of the Mercaptans.—The mercaptans are colourless liquids, mostly insoluble in water, and possess a disagreeable, garlic-like odour.

(1) Moderate oxidation with concentrated sulphuric acid, sulphuryl chloride, or iodine converts the mercaptans or mercaptides into disulphides (p. 144). The reaction with iodine permits of these substances being titrated (B. **39**, 738).

(2) When oxidized with nitric acid, the mercaptans yield the sulphonic acids. Conversely, the mercaptans result by the reduction of the sulphonic acids.

(3) By their union with aldehydes and ketones there result *mercaptals* and *mercaptols*—*e.g.* $CH_3CH(SC_2H_5)_2$, $(CH_3)_2C(SC_2H_5)_2$—which will be treated at the conclusion of the aldehydes and ketones (*q.v.*).

(4) The mercaptans unite more or less easily to an ethylene linkage, forming sulphides (B. **38**, 646).

Ethyl Mercaptan, $C_2H_5.SH$, b.p. 36°; $D_{20} = 0{\cdot}829$. It is the most important and was the first discovered mercaptan (1834, *Zeise*, A. **11,** 1). Despite its revolting odour, it is technically made from ethyl chloride and potassium sulphydrate in the preparation of *sulphonal*. It is but slightly soluble in water; readily in alcohol and ether.

Mercury Mercaptide $(C_2H_5.S)_2Hg$, m.p. 86°, crystallizes from alcohol in brilliant leaflets, and is only slightly soluble in water. When mercaptan is mixed with an alcoholic solution of $HgCl_2$, the compound $C_2H_5.S.HgCl$ is precipitated. The potassium and sodium compounds are best obtained by dissolving the metals in mercaptan diluted with ether; they crystallize in white needles.

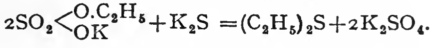
Methyl Mercaptan, CH_3SH,	b.p. 6°;	n-*Butyl Mercaptan*	b.p. 98°;
n-*Propyl Mercaptan*	b.p. 68°;	*Allyl Mercaptan,* C_3H_5SH,	b.p. 90°.
Isopropyl Mercaptan	b.p. 59°;		

Methyl Mercaptan is formed during the fermentation of proteins (B. **34**, 201). n-*Butyl Mercaptan* is found in secretions of the stink-badger of the Philippines (*Mydäus Marchei Huet*) (Pharm. Centralhalle, 1896, No. 34).

B. **Sulphides or Thio-ethers** are obtained like the mercaptans:

1. By the action of alkylogens on potassium sulphide.
2. By distillation of salts of the ethyl sulphuric acids with potassium sulphide.
3. By the action of P_2S_5 on ethers.
4. On heating the lead mercaptides:

1. $$2C_2H_5Cl + K_2S = (C_2H_5)_2S + 2KCl.$$

2. 

$$2SO_2{<}^{O.C_2H_5}_{OK} + K_2S = (C_2H_5)_2S + 2K_2SO_4.$$

3. $$5(C_2H_5)_2O + P_2S_5 = 5(C_2H_5)_2S + P_2O_5.$$

4. $$(C_2H_5S)_2Pb = (C_2H_5)_2S + PbS.$$

Further, by the interaction of alkyl halides with potassium or sodium mercaptides, when mixed thio-ethers are also produced:

5. $$C_2H_5SNa + C_2H_5I = (C_2H_5)_2S + NaI$$
$$C_2H_5SNa + C_3H_7I = C_2H_5.S.C_3H_7 + NaI.$$

Methods 1, 2, and 5 are analogous to those used in the preparation of the corresponding ethers.

The sulphides, like the mercaptans, are colourless liquids, insoluble in water, but easily soluble in alcohol and ether. When impure their odour is very disagreeable, but is ethereal when pure (B. **27**, 1239).

Reactions.—The sulphides are characterized by their additive power. (1) They unite with Br_2, and (2) with metallic chlorides—*e.g.* $(C_2H_5)_2S.HgCl_2$, $[(C_2H_5)_2S]_2$—$PtCl_4$ (C. 1900, I. 280; 1901, II. 184); (3) also with iodo-alkyl to form sulphine iodides (p. 145); (4) they are oxidized to sulphoxides (p. 145) and sulphones (p. 145) by nitric acid.

Methyl Sulphide, $(CH_3)_2S$, b.p. 37·5°.

Ethyl Sulphide, $(C_2H_5)_2S$, b.p. 91°.

n-*Propyl Sulphide*, $(C_3H_7)_2S$, b.p. 130–135°; n-*Butyl Sulphide*, b.p. 182°; *Isobutyl Sulphide*, $[(CH_3)_2CH.CH_2]_2S$, b.p. 173°; *Cetyl Sulphide*, $(C_{16}H_{33})_2S$, m.p. 57°.

The sulphides of vinyl and allyl alcohols occur in nature. They are far more important than the sulphides of the normal alcohols, particularly allyl sulphide.

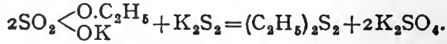
Vinyl Sulphide, $(C_2H_3)_2S$, b.p. 101°; D = 0·9125, is the principal ingredient of the oil of *Allium ursinum*, and is very similar to allyl sulphide. It forms $(C_2H_3Br_2)_2SBr_2$ with six atoms of bromine. Silver oxide changes it to vinyl ether (p. 129) (A. **241**, 90).

Allyl Sulphide, $(C_3H_5)_2S$, b.p. 140°, may be prepared by digesting allyl iodide with potassium sulphide in alcoholic solution. It is a colourless, disagreeable smelling oil, but slightly soluble in water. It forms crystalline precipitates with alcoholic solutions of $HgCl_2$ and $PtCl_4$. With silver nitrate it yields the crystalline compound $(C_3H_5)_2S.2AgNO_3$.

The early statement of *Wertheim* that allyl sulphide is to be found in garlic, has not been substantiated; it is the disulphide which occurs there (C. 1892, II. 833).

Allyl mustard oil is produced by heating the mercury derivative with potassium thiocyanate. Vinyl mustard oil is prepared in an analogous manner.

C. **Alkyl Disulphides** are produced (1) like the alkyl monosulphides by distilling salts of the ethyl sulphuric acids or alkylogens with potassium disulphide (C. 1901, I. 1363); (2) by the action of iodine on mercaptans, or concentrated sulphuric acid on mercaptides (B. **39**, 738); (3) by the action of sulphuryl chloride on the mercaptans:

1. 

$$2SO_2{<}\begin{smallmatrix}O.C_2H_5\\OK\end{smallmatrix}+K_2S_2=(C_2H_5)_2S_2+2K_2SO_4.$$

2. $$2C_2H_5SH+I_2=C_2H_5S{-}S{-}C_2H_5+2HI.$$

3. $$2C_2H_5SH+SO_2Cl_2=(C_2H_5)_2S_2+SO_2+2HCl.$$

When bromine acts on a mixture of two mercaptans, mixed alkyl disulphides are produced (B. **19**, 3132). Nascent hydrogen reduces the alkyl disulphides to mercaptans, whilst zinc dust converts them into zinc mercaptides:

$$(C_2H_5)_2S_2+Zn=(C_2H_5S)_2Zn.$$

Mercaptides result on heating the disulphides with potassium sulphide (B. **19**, 3129); magnesium alkyl halides produce sulphides and mercaptides (C. 1906, I. 1244), and dilute nitric acid changes them to alkyl thiosulphonic esters (p. 147).

Methyl Disulphide, $(C_2H_3)_2S_2$, b.p. 112°, and *Ethyl Disulphide*, $(C_2H_5)_2S_2$, b.p. 151°, are oils possessing an odour like that of garlic.

Allyl Disulphide, $(C_3H_5)_2S_2$, b.p.$_{16}$ 117°, occurs with closely connected polysulphides in garlic, *Allium sativum* (C. 1892, II. 833). The name "allyl" is derived from this.

D. **Sulphine** or **Sulphonium Compounds** (B. **27**, 505 *Anm.*). (1) The sulphides of the alcohol radicals (thio-ethers) combine with the iodides, bromides, and chlorides of the alcohol radicals at ordinary temperatures, more rapidly on application of heat, and form crystalline compounds:

$$(C_2H_5)_2S+C_2H_5I=(C_2H_5)_3\overset{IV}{S}I.$$

Triethyl Sulphonium Iodide.

These are perfectly analogous to the halogen derivatives of the strong basic radicals. By the action of moist silver oxide the halogen atom in them may be replaced by hydroxyl, and hydroxides similar to potassium hydroxide are formed:

$$(C_2H_5)_3SI+AgOH=(C_2H_5)_3S.OH+AgI.$$

(2) The sulphine or sulphonium halides are also obtained on heating the sulphur ethers with the halogen acids, and (3) the alkyl sulphides with iodine (B. **25**, R. 641):

$$2(C_2H_5)_2S+HI=(C_2H_5)_3SI+C_2H_5SH.$$
$$4(CH_3)_2S+I_2=2(CH_3)_3SI+(CH_3)_2S_2.$$

(4) The acid chlorides react similarly to iodine.
(5) By the action of iodomethane on metallic sulphides:

$$SnS+3CH_3I=SnI_2+(CH_3)_3SI.$$

By heating together sulphur and iodomethane to 180° there is formed $(CH_3)_3SI.I_2$ an iodine addition product of trimethyl sulphonium iodide. Similar compounds are obtained with selenium and tellurium (C. 1904, II. 414).

Often when the iodoalkyls act on the sulphides of higher alkyls the latter are displaced (B. **8**, 825).

$(C_2H_5)_2S.CH_3I$ and $\genfrac{}{}{0pt}{}{CH_3}{C_2H_5}{>}S.C_2H_5I$ are not isomeric (in which case a difference of the 4 valences of S would be proved) but identical (B. **22**, R. 648).

The sulphonium hydroxides are crystalline, efflorescent, strongly basic bodies, readily soluble in water. Like the alkalis, they precipitate metallic hydroxides from metallic salts, set ammonia free from ammoniacal salts, absorb CO_2 and saturate acids, with the formation of neutral salts:

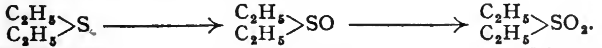
$$(C_2H_5)_3S.OH+HNO_3=(C_2H_5)_3S.NO_3+H_2O.$$

We thus observe that relations similar to those noted with the nitrogen group prevail with sulphur (also with selenium and tellurium). Nitrogen and phosphorus combine with four hydrogen atoms, also with alcoholic radicals, to form the groups ammonium, NH_4, and phosphonium, PH_4, which yield compounds similar to those of the alkali metals. Sulphur and its analogues combine in like manner with three univalent alkyls, and give sulphonium and sulphine derivatives. Other non-metals and the less positive metals, like lead and tin, exhibit a perfectly similar behaviour. By addition of hydrogen or alkyls they acquire a strongly basic, metallic character (see the metallo-organic compounds and also the aromatic iodonium bases, Vol. II.).

Trimethyl Sulphonium Iodide, $(CH_3)_3SI$, is readily soluble in water, but is soluble with difficulty in alcohol, from which it crystallizes in white needles. At 215° it breaks down directly into methyl sulphide and iodomethane. Platinic chloride precipitates, from solutions of the chloride, a chloroplatinate, $[(CH_3)_3SCl]_2.PtCl_4$, very similar to ammonium platinum chloride. **Trimethyl Sulphonium Hydroxide,** $(CH_3)_3SOH$, consists of deliquescent crystals possessing a strongly alkaline reaction.

Consult B. **24**, R. 906, for the refractive power and the lowering of the freezing point of sulphine compounds.

E. Sulphoxides and Sulphones, as mentioned (p. 143), result from the oxidation of the sulphides with nitric acid:

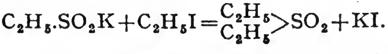


$$\genfrac{}{}{0pt}{}{C_2H_5}{C_2H_5}{>}S \longrightarrow \genfrac{}{}{0pt}{}{C_2H_5}{C_2H_5}{>}SO \longrightarrow \genfrac{}{}{0pt}{}{C_2H_5}{C_2H_5}{>}SO_2.$$

Ethyl Sulphide. Ethyl Sulphoxide. Ethyl Sulphone.

The *sulphoxides* may be compared with the ketones. Nascent hydrogen reduces them to sulphides. **Methyl** and **Ethyl Sulphoxides** are thick oils, which combine with nitric acid: $(CH_3)_2SO.HNO_3$. Barium carbonate liberates the sulphoxides from these salts. **Methyl Sulphoxide** is also formed when silver oxide acts upon *methyl sulphobromide,* $(CH_3)_2SBr_2$.

The *sulphones,* obtained from the sulphoxides by means of fuming nitric acid, or by oxidation with potassium permanganate, may also be regarded as esters of the alkyl sulphinic acids (*q.v.*), because they can be prepared from salts of the latter through the action of iodoalkyls:



$$C_2H_5.SO_2K+C_2H_5I=\genfrac{}{}{0pt}{}{C_2H_5}{C_2H_5}{>}SO_2+KI.$$

However, they are not true esters, but compounds, characterized by great stability, in which both alcohol radicals are linked to sulphur. They cannot be reduced to sulphides.

Methyl Sulphone, $(CH_3)_2SO_2$, m.p. 109°; b.p. 238°.
Ethyl Sulphone, $(C_2H_5)_2SO_2$, m.p. 70°; b.p. 248°.

ALKYL SULPHONIC ACIDS, ALKYL THIOSULPHURIC ACIDS, ALKYL THIOSULPHONIC ACIDS, AND ALKYL SULPHINIC ACIDS

These compounds have the general formulæ:

$R.SO_2OH$	$RS.SO_3H$	$R.SO_2SH$	$R.SO_2H$
$C_2H_5.SO_2OH$	$C_2H_5S.SO_3H$	$C_2H_5.SO_2SH$	$C_2H_5.SO_2H.$
Ethyl Sulphonic Acid.	Ethyl Thiosulphuric Acid.	Ethyl Thiosulphonic Acid.	Ethyl Sulphinic Acid.

F. Sulphonic Acids.

The sulpho-acids or sulphonic acids contain the *sulpho-group*—$SO_2.OH$—joined to carbon. This is evident from their production by the oxidation of the mercaptans, and from their re-conversion into mercaptans (p. 142). They can be considered as being ester derivatives of the unsymmetrical sulphurous acid, HSO_2OH (p. 140).

Formation.—(1) Their salts result from the interaction of alkali sulphites and alkyl iodides; their esters are formed when alkyl iodides act on silver sulphite:

$$K.SO_2OK+C_2H_5I=\underset{\text{Potassium Ethyl Sulphonate.}}{C_2H_5.SO_2OK}+KI.$$

$$Ag.SO_2OAg+2C_2H_5I=\underset{\text{Ethyl Sulphonic Ethyl Ester.}}{C_2H_5.SO_2OC_2H_5}+2AgI.$$

All the esters of sulphurous acid, both sulphite, $ROSO_2K$, and sulphonic esters, $(RO)_2SO$, when heated with KI form sulphonic acid double salts of the type $(RSO_3K)_4KI$.

(2) By oxidation of (*a*) the mercaptans; (*b*) the alkyl disulphides; (*c*) the alkyl thiocyanates with nitric acid:

$$\left.\begin{array}{r} C_2H_5SH \\ [C_2H_5S]_2 \\ C_2H_5S.CN \end{array}\right\} \xrightarrow{O} C_2H_5.SO_3H.$$

(3) The alkyl sulphinic acids are readily oxidized to sulphonic acids.

(4) The sulpho-acids can be formed further by the action of sulphuric acid or sulphur trioxide on alcohols, ethers, and various other bodies. This reaction is very common with benzene derivatives and proceeds without difficulty.

Properties and Reactions.—These acids are thick liquids, readily soluble in water, and generally crystallizable. They undergo decomposition when exposed to heat (B. **38**, 2019), but are not altered when boiled with alkali hydroxides. When fused with solid alkali hydroxides they break up into *sulphites* and alcohols:

$$C_2H_5.SO_2.OK+KOH=KSO_2.OK+C_2H_5.OH.$$

PCl_5 changes them to chlorides,—*e.g.* $C_2H_5.SO_2Cl$,—which are reduced to mercaptans by hydrogen; and by the action of sodium alcoholates they pass into the neutral esters—$C_2H_5.SO_3.C_2H_5$ (p. 138).

Many of these reactions plainly indicate that in the sulphonic acids the sulphur is directly combined with the alkyl groups, and that very probably, therefore, in the sulphites the *one* metallic atom is directly united to sulphur. The sulphonic esters boil considerably higher than the esters of symmetrical sulphurous acid (p. 140). Whilst alcoholic potassium hydroxide converts the latter into potassium sulphite and alcohol, alkali solutions act only with difficulty and with the partial production of salts of alkyl sulphonic acid; in the sulphonic esters the alkyl group which is not directly combined with sulphur is readily removed by hydrolysis.

Methyl Sulphonic Acid, $CH_3.SO_3H$, was synthetically prepared by *Kolbe* in 1845 from carbon disulphide, by converting it by means of moist chlorine into the chloride of *trichloromethyl sulphonic acid*, CCl_3SO_2Cl, and this into the acid itself, which is reduced by sodium amalgam to methyl sulphonic acid (A. **54**, 174):

$$C+2S=CS_2 \longrightarrow CCl_3.SO_2Cl \longrightarrow CCl_3.SO_3H \longrightarrow CH_3.SO_3H.$$

Methyl Sulphochloride CH_3SO_2Cl, b.p. 160°; *Ethyl Sulphonate*, b.p.$_{10}$ 86°; *Methyl Sulphonic Anhydride* $(CH_3SO_2)_2O$, m.p. 71°, b.p.$_{10}$ 138° (B. **38**, 2018).

Ethyl Sulphonic Acid, $C_2H_5.SO_3H$, is oxidized by concentrated nitric acid to *ethyl sulphuric acid*, $C_2H_5O.SO_3H$ (p. 139); *lead salt*, $(C_2H_5.SO_3)_2Pb$, is readily soluble; *methyl ester*, $C_2H_5SO_3CH_3$, b.p. 198°; *ethyl ester*, $C_2H_5.SO_3.C_2H_5$, b.p. 213·4°; *ethyl sulphochloride*, $C_2H_5.SO_2Cl$, b.p. 177°.

Ethylene Sulphonic Acid, *Vinyl Sulphonic acid*, $CH_2{=}CHSO_3H$, is obtained from ethane disulphochloride, by the action of water and alcohol. Its *ammonium salt*, m.p. 156°, reduces alkaline permanganate instantaneously, and combines with ammonium hydrogen sulphite to form ammonium ethane disulphonate (C. 1898, II. 1009; 1899, I. 1104). *Ethylene Sulphone Anilide*, $CH_2:CHSO_2NHC_6H_5$, and *Propylene Sulphone Anilide*, $CH_3CH:CHSO_2NHC_6H_5$, are obtained from the respective α and β-alkyl disulphochlorides and aniline with the separation of SO_2 and HCl, which takes place even at 0° (B. **36**, 3626).

G. Alkyl Thiosulphuric Acids.

(1) The well-crystallized alkali salts of these acids are made by acting on alkali thiosulphates with primary saturated alkyl iodide (B. **7**, 646, 1157) or bromide (B. **26**, 996).

$$C_2H_5I + NaS.SO_3Na = C_2H_5S.SO_3Na + NaI.$$

Sodium ethyl thiosulphate is called *Bunte's salt*, after its discoverer. (2) It also results when iodine acts on a mixture of sodium mercaptide and sodium sulphite:

$$C_2H_5SNa + NaSO_3Na + I_2 = C_2H_5S.SO_3Na + 2NaI.$$

The free acids are not stable. Mineral acids convert sodium ethyl thiosulphate into mercaptan and mono-sodium sulphate. Heat breaks down the salts into disulphides, neutral potassium sulphate, and sulphur dioxide. Electroylsis of Bunte's salt give rise to diethyl disulphide (C. 1901, I. 331).

H. The Alkyl Thiosulphonic Acids.

These acids are only stable as salts and esters. They are formed by the action of the chlorides of sulpho-acids on potassium sulphide:

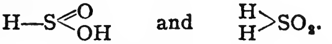
$$C_2H_5.SO_2Cl + K_2S = C_2H_5.SO_2SK + KCl.$$

The *esters*, $R.SO_2SR$, of this new class were formerly called *alkyl disulphoxides*, $R_2S_2O_2$, and are obtained (1) from the alkali salts by the action of the alkyl bromides (B. **15**, 123):

$$C_2H_5.SO_2.SK + C_2H_5Br = C_2H_5.SO_2.SC_2H_5 + KBr;$$

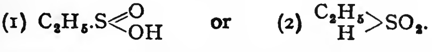
and (2) by the oxidation of mercaptans and alkyl disulphides with dilute nitric acid: $(C_2H_5)_2S_2 + O_2 = C_2H_5.SO_2.SC_2H_5$. These esters are liquids, insoluble in water, and possessed of a disgusting odour (B. **19**, 1241, 3131). **Ethyl Thiosulphuric Ethyl Ester,** $C_2H_5.SO_2.S.C_2H_5$, b.p. 130–140°.

I. Alkyl Sulphinic Acids The hydrosulphites (see Inorganic Chemistry) can be looked upon as being salts of a mixed acid anhydride of sulphurous acid and a hypothetical *Sulphoxylic acid*, whereby the two following structural formulæ are possible:



$$H{-}S{<}^{O}_{OH} \quad \text{and} \quad {}^{H}_{H}{>}SO_2.$$

Replacing one hydrogen atom, the sulphinic acids result, *e.g.*,



$$(1)\ C_2H_5.S{<}^{O}_{OH} \quad \text{or} \quad (2)\ {}^{C_2H_5}_{H}{>}SO_2.$$

The true alkyl sulphinic esters are derived from the first formula, whilst the sulphones can be referred to the second formula (p. 145). The sulphinates are produced as follows:

(1) By the oxidation of the dry sodium mercaptides in the air.

(2) When SO_2 acts on the zinc alkyls, or magnesium alkyl halides; or when SO_2Cl_2 acts on magnesium alkyl halides (B. **37**, 2152; C. 1905, I. 1143).

(3) When zinc acts on the chlorides of the sulphonic acids

(1) $C_2H_5SNa+2O=C_2H_5SO_2Na.$

(2) $(C_2H_5)_2Zn+2SO_2=(C_2H_5SO_2)_2Zn.$

$2C_2H_5MgI+SO_2Cl_2=C_2H_5SO_2MgI+C_2H_5Cl+MgICl.$

(3) $2C_2H_5SO_2Cl+2Zn=(C_2H_5SO_2)_2Zn+ZnCl_2.$

The sulphones (p. 145) are produced in the action of iodoalkyls on the alkali sulphonates, whilst the *real esters* result from the etherification of the acids with alcohol and hydrochloric acid, or by the action of chlorocarbonic esters on the sulphinates (B. **18**, 2493):

$$R.SO_2Na+Cl.CO_2R=R.SO.OR+CO_2+NaCl.$$

When these esters are hydrolyzed by alcohol or water they break down into alcohol and sulphinic acid, whilst the isomeric sulphones are not altered. The free sulphinic acids are not very stable. They rapidly dissolve in water and are oxidized to sulphonic acids. Potassium permanganate and acetic acid convert the sulphinic esters into sulphonic esters (B. **19**, 1225), whereas the isomeric sulphones remain unchanged.

4. SELENIUM AND TELLURIUM COMPOUNDS

These are perfectly analogous to the sulphur compounds.

Ethyl Hydroselenide, $C_2H_5.SeH$, is a colourless, unpleasant-smelling, very mobile liquid. It combines readily with mercuric oxide to form a mercaptide.

Ethyl Selenide, $(C_2H_5)_2Se$, b.p. 108°, is a heavy, yellow oil. It unites directly with the halogens, *e.g.* $(C_2H_5)_2SeCl_2$. It dissolves in nitric acid with formation of the oxide, $(C_2H_5)_2SeO$, which yields the salt, $(C_2H_5)_2Se(NO_3)_2$. **Ethyl selenite,** $SeO(OC_2H_5)_2$, b.p. 184°, with slight decomposition, is prepared from selenyl chloride and sodium ethoxide, or from silver selenite and iodo-ethane. These reactions demonstrate that the selenites have the constitution $SeO(OMe)_2$, and that selenious acid is a true dihydroxy-acid (A. **241**, 150).

Tellurium mercaptans are not known. **Methyl Telluride,** $(CH_3)_2Te$, b.p. 80–82°, and **Ethyl Telluride,** $(C_2H_5)_2Te$, b.p. 137·5°, are obtained by distilling barium alkyl sulphate with potassium telluride. They are heavy, yellow oils. The following compounds are derived from them: $(CH_3)_2TeO$, $(CH_3)_2.TeCl_2$, $(CH_3)_2Te(NO_3)_2$, $(CH_3)_3TeI$, $(CH_3)_3Te.OH$, etc.

Dimethyl Tellurium Oxide, $(CH_3)_2TeO$, is a crystalline efflorescent compound, resembling, in its basic properties, CaO and PbO. It reacts strongly alkaline, expels ammonia from ammonium salts, and neutralizes acids.

5. NITROGEN DERIVATIVES OF THE ALCOHOL RADICALS

A I. MONONITRO-PARAFFINS AND OLEFINES, HALOGEN MONONITRO-PARAFFINS

By nitro-bodies are understood compounds of carbon in which the hydrogen combined with the latter is replaced by the univalent nitro-group, NO_2. The carbon is directly united to the nitrogen, as is shown by the reduction of the nitro-derivatives yielding amido-compounds:

$$R.NO_2+6H=R.NH_2+2H_2O.$$

In the aromatic series the hydrogen atoms of the benzene nucleus are readily replaced by nitro-groups, *e.g.*:

$$C_6H_6+NO_2OH=\underset{\text{Nitrobenzene.}}{C_6H_5NO_2}+H_2O.$$

Comparative refractometric investigations have shown that the nitro-group in nitroethane, and that in nitrobenzene, do not have the same structure (Z. ph. Ch. **6**, 552). See B. **28**, R. 153, for the heat of combustion of the nitro-paraffins.

(1) Normal paraffins are very stable towards nitric acid (p. 77), and are only acted on after prolonged heating at 130–140° with

the dilute acid, whereby substitution products result (*Konowalow*, B. **26,** R. 108; B. **28,** 1863; C. 1898, I. 926; 1899, I. 966, 1063; 1902, I. 564; 1906, II. 312).

Experience shows that, amongst the fatty bodies, the hydrogen atom which is attached to a tertiary carbon atom is more easily replaced by the nitro-group than that which is attached to a secondary carbon atom, and this, in turn, more easily than one attached to a primary. Amongst secondary compounds, that hydrogen is the more easily replaced if its carbon atom is connected to a tertiary radical. *Markownikoff* has expressed this in the following rule: In hydrocarbons that hydrogen is always more easily replaced when attached to a carbon atom which is affected by other carbon atoms (B. **33,** 1907).

(2) A common method for the preparation of the mononitro-derivatives of fatty hydrocarbons—the **nitro-paraffins**—consists in heating the iodides of the alcohol radicals with silver nitrite (*V. Meyer*, 1872) (A. **171,** 1; **175,** 88; **180,** 111):

$$C_2H_5I + AgNO_2 = C_2H_5.NO_2 + AgI.$$

The isomeric esters of nitrous acid, such as $C_2H_5.O.NO$, are formed in this reaction (B. **15,** 1547). From this we would infer that silver nitrite conducted itself as if apparently consisting of $AgNO_2$ and Ag.O.NO. Potassium nitrite does not act like $AgNO_2$ (see Mode of Formation 3) (C. 1907, I. 235). It would appear that the formation of esters is influenced by the production of alkylens, which afterwards form esters by the union with HNO_2 (A. **180,** 157; B. **9,** 529). Possibly the alkylogens unite directly with the nitrogen, or in consequence of an opening-up of the double N=O union.

(3) Simultaneously with the discovery of method 2, *Kolbe* demonstrated that nitromethane resulted from the action of potassium nitrite on chloracetic acid. The first product in this instance was nitroacetic acid, which broke down into carbon dioxide and nitromethane (J. pr. Ch. [2] **5,** 427):

$$CH_2Cl.CO_2H \longrightarrow [CH_2(NO_2).CO_2H] \longrightarrow CH_3NO_2 + CO_2.$$

By the same method *a*-bromopropionic acid and *a*-bromobutyric acid are made to yield nitroethane and nitropropane, and so on for the series (C. 1900, I. 126).

(4) The nitro-paraffins are also formed by oxidation of the nitroso-paraffins (p. 152).

(5) By a *nucleus-synthesis:* Zinc alkyls, acting on chloro- and bromo-nitro-paraffins, produce mononitro-paraffins (B. **26,** 129):

$$CH_3.CHBrNO_2 \xrightarrow{Zn(CH_3)_2} CH_3.CH(NO_2).CH_3, \text{ Secondary Nitropropane.}$$

$$CCl_3.NO_2 \xrightarrow{Zn(CH_3)_2} C.NO_2(CH_3)_3, \text{ Tertiary Nitrobutane.}$$

Properties and Reactions.—The nitro-paraffins are colourless, agreeably smelling liquids, which are sparingly soluble in water. They distil without decomposition, and only explode with difficulty. Their boiling points lie considerably higher than those of the corresponding nitrous esters (p. 137).

The action of potassium and sodium hydroxides on the nitro-paraffins is to form salts when the NO_2 group stands next to a hydrogen atom in the molecule. Similar action on the isomeric nitrous esters results in the production of alcohol and an alkali nitrite.

Victor Meyer, who discovered the nitro-paraffins and studied them closely, assumed that, in the salts, the alkali metal was united directly with the carbon atom (A. **171,** 28, 48); whilst *A. Michael* (J. pr. Ch. (1888), [2] **37,** 507) and later *Nef* (A. (1894), **280,** 263) showed it to be joined to an oxygen atom of the nitro-group.

Potassium-nitroethane, CH_3CHKNO_2	$CH_3.CH{=}NOOK.$
According to *V. Meyer*.	According to *A. Michael*.

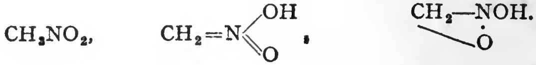
The nitro-paraffins are converted by alkalis into isonitro-paraffins (also called *aci*-nitro-paraffins or nitronic acids), from which the salts are derived (compare p. 41). If a solution of such an alkali salt is acidified, the isonitro-paraffin which is first precipitated changes into the corresponding nitro-paraffin. *A. F. Holleman* (compare B. **33**, 2913) showed how this change could be followed by rapidly taken conductivity measurements, since the labile, salt-forming isonitro-body is an electrolyte, which turns into a stable, neutral, non-conducting nitro-compound. The rapidly falling conductivity runs parallel to the decolorization of the first formed yellow solution. *Hantzsch* succeeded in isolating phenylnitromethane in both its forms—$C_6H_5CH_2NO_2$ and $C_6H_5CH:NOOH$ (B. **29**, 1223, 2251; C. 1897, I. 1054).

If a solution of an alkali salt of a primary nitro-paraffin is dropped into ice-cold dilute hydrochloric acid, a small proportion is converted into a hydroxamic acid. For instance, potassium pseudonitromethane changes into acetohydroxamic acid (*Bamberger*, B. **35**, 49).

By gradual reduction, the nitro-bodies (*V. Meyer*, B. **24**, 3528, 4243; **25**, 1714) pass first into alkyl hydroxylamines (p. 171) and then into primary amines:

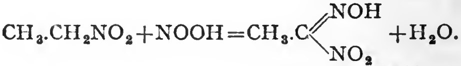
$$\underset{\text{Nitromethane.}}{CH_3NO_2} \longrightarrow \underset{\text{Methyl Hydroxylamine.}}{CH_3.NH.OH} \longrightarrow \underset{\text{Methylamine.}}{CH_3NH_2.}$$

The conversion of nitro-paraffins into primary amines proves, as indicated before, that the nitrogen of the nitro-group present in them is linked to carbon. For nitromethane we have the choice between the following formulæ (comp. B. **29**, 2263):



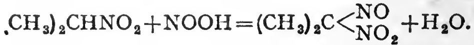
$$CH_3NO_2, \qquad CH_2{=}N\begin{matrix}\diagup OH\\ \diagdown O\end{matrix}, \qquad \begin{matrix}CH_2\text{—}NOH.\\ \diagdown\!\!\text{——}O\end{matrix}$$

The varying behaviour of the nitro-paraffins with nitrous acid at the moment of its formation from potassium nitrite and sulphuric acid is very interesting, according as the nitro-group is linked to primary, secondary, or tertiary radicals. Primary nitro-compounds in the presence of excess of potassium hydroxide give rise to an *intense red* colour due to a soluble, red-coloured alkali salt of a **nitrolic acid**, whilst the nitro-compounds of the secondary radicals yield a *dark blue* coloration, due to the formation of a **pseudo-nitrole**:



$$CH_3.CH_2NO_2 + NOOH = CH_3.C\begin{matrix}\diagup\!\!\!\diagup NOH\\ \diagdown NO_2\end{matrix} + H_2O.$$

Ethyl Nitrolic Acid
(Nitroacetoxime).



$$(CH_3)_2CHNO_2 + NOOH = (CH_3)_2C{<}\begin{matrix}NO\\ NO_2\end{matrix} + H_2O.$$

Propyl Pseudonitrol.

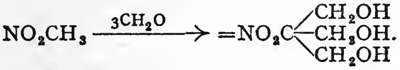
The nitro-compounds of tertiary radicals do not react with nitrous acid. Since the alcohols easily form iodides which react with silver nitrate, the preceding reactions serve as a means of distinguishing primary, secondary, and tertiary alcoholic radicals from one another (p. 109).

Chlorine and bromine, acting on the alkali salts of primary and secondary nitro-paraffins, produce chloro- and bromo-nitro-substitution products. In them the halogen atom occupies the same position as the nitro-group.

Diazobenzene salts, acting on the alkali salts of the primary nitro-paraffins, give nitrohydrazones (nitro-azoparaffins), *e.g.* *nitroacetaldehyde hydrazone*, $CH_3C(NO_2):N.NHC_6H_5$, results from potassium nitroethane and diazobenzene nitrate (B. **31**, 2626; see also Vol. II.).

Primary and secondary nitro-paraffins unite with aldehydes in the presence of alkali carbonates to form nitro-alcohols. As many molecules of an aldehyde unite with one molecule of a nitro-paraffin as there are hydrogen atoms united to the carbon atom to which the nitro-group is attached. The nitro-alcohols, as obtained by this method, will be described with the polyatomic alcohols (C. 1897,

II. 1000). Nitromethane and formaldehyde give rise to nitrobutyl glycerol, the parent substance for the synthesis of glycerol:



$$NO_2CH_3 \xrightarrow{3CH_2O} =NO_2C\begin{cases}CH_2OH\\CH_3OH.\\CH_2OH\end{cases}$$

1,1-Haloid nitro-paraffins also condense with aldehydes to form meso-halogen nitro-paraffins, which were described under the section of the nitrogen derivatives of the ketone-alcohols or ketols.

For compounds resulting from the action of sodium ethoxide and the alkyl iodides on the nitroethanes, see B. **21**, R. 58 and 710.

Zinc ethyl converts nitroethane into β-ethyl β-sec.-butyl hydroxylamine (B. **34**, 2500).

Primary Mononitroparaffins: Nitromethane, CH_3NO_2, b.p. 101°, is isomeric with formhydroxamic acid. *Sodium* and *potassium nitromethane* explode with great violence when they are heated; this also occurs when these substances, dried in a desiccator, come into contact with traces of water (B. **27**, 3406). When mercuric chloride acts on sodium nitromethane, mercury fulminate is produced (*q.v.*) (A. **280**, 275). By the action of potassium hydroxide on nitromethane or of hydroxylamine hydrochloride on sodium nitromethane, *Methazonic Acid*, $CH_2 : N(O).CH : N(O)OH$, m.p. 79°, is formed. It is a mono-basic acid derived from formic acid (B. **34**, 867). *Nitroethane*, CH_3CH_2NO, b.p. 113°; reaction between the sodium salt, $CH_3CH : NOONa$, and benzoyl chloride leads to the formation of benzoyl acetohydroxamic acid, $CH_3.C(OH)NO.COC_6H_5$, and not to the expected benzoyl isonitroethane (C. 1898, I. 564); 1-*Nitropropane*, $CH_3.CH_2.CH_2NO_2$, b.p. 130°; 1-*Nitro-n.-butane*, $CH_3.CH_2.CH_2.CH_2.NO_2$, b.p. 151°; *Nitroisobutane*, $(CH_3)_2CH.CH_2NO_2$, b.p. 137–140°; *Nitro-n.-octane*, $CH_2.[CH_2]_6.CH_2.NO_2$, b.p. 205–210°.

Secondary Mononitroparaffins: *Isonitropropane*, $(CH_3)_2CHNO_2$, b.p. 118°; *Secondary Nitrobutane*, $\genfrac{}{}{0pt}{}{C_2H_5}{CH_3}{>}CHNO_2$, b.p. 138°.

Tertiary Mononitroparaffins: *Tertiary Nitrobutane*, $(CH_3)_3C.NO_2$, b.p. 126°; 2-*Nitro*-2-*Methyl Butane*, $(CH_3)_2C(NO_2)C_2H_5$, b.p. 150° (C. 1903, I. 625).

Nitro-olefines.—Nitro-alcohols, obtained by the condensation of aldehydes with nitromethane (comp. p. 150), give up water under the action of zinc chloride, and form nitro-olefines, $RCH : CHNO_3$; *Nitroisohexylene* $(CH_3)_2CHCH_2CH : CHNO_2$, b.p.$_{10}$ 80°; *Nitro-octylene*, $C_6H_{13}CH : CHNO_2$, b.p.$_8$ 114°. *Nitroisobutylene*, $(CH_3)C : CHNO_2$, is prepared by the action of fuming nitric acid on isobutylene; and also by the abstraction of CO_2 by alkali from dimethyl-α-nitroacrylic acid. Reduction of the nitro-olefines results in the formation of the oximes of the paraffin aldehydes (p. 152) (C. 1903, II. 553).

Nitropropylene, $CH_2 : CH.CH_2NO_2$. b.p.$_{180}$ 88° (C. 1898, I. 192).

Halogen Nitro-compounds result (1) from di-halogen paraffins in which two different halogen atoms are attached to two C-atoms in the same chain, such as $CH_2Cl.CH_2.CH_2Br$, reacting with a mono-molecular quantity of silver nitrate; (2) from nitro-paraffins and Cl or Br; (3) from nitro-alcohols and PCl_5. These substances are acidic in character when a H-atom is united to the same C-atom as the nitro-group. The remarks which have been made on the constitution of the salts of the mononitro-paraffins hold good for the salts of the halogen-nitro-compounds (p. 149).

Chloronitromethane, CH_2ClNO_2, b.p. 122°; *Bromonitromethane*, b.p. 146° (B. **29**, 1823); *Dibromonitromethane* (B. **29**, 1824).

1,1-*Chloronitroethane*, $CH_3.CHClNO_2$, b.p. 124°; 1,1 *Bromonitroethane*, b.p. 146°; 1,2-*Chloronitroethane*, $ClCH_2.CH_2NO_2$, b.p. 173°; 1,1,1-*Dibromonitroethane*, $CH_3.CBr_2NO_2$, b.p. 165°.

1,1-*Chloronitropropane*, $CH_3CH_2CHClNO_2$, b.p. 141°; 1,1-*Bromonitropropane*, b.p. 165°; 1-*Nitro*-2-*chloropropane*, b.p. 172°; 1-*Chloro*-2-*nitropropane*, b.p. 170°; 1-*Chloro*-3-*nitropropane*, b.p. 197°; 2,2-*Chloronitropropane*, $CH_3CCl(NO_2).CH_3$, b.p. 133°; 1,2-*Bromonitropropane*, b.p. 165°; 1,1,1-*Dibromonitropropane*, b.p. 185°.

Nitrotriiodoethylene, $CI_2 : CINO_2$, m.p. 109°, and *Dinitrotriiodoethylene*, $NO_2CI : CINO_2$, result from the action of fuming nitric acid or N_2O_3 on diiodoacetylene and tetraiodoethylene respectively (B. **33**, 2190).

Following the scheme on which this work is planned, the nitro-halogen compounds should take their places after the aldehydes, ketones, carboxylic acids and glycols, according to the position of the substituting atom and group. It is, however, more convenient not to divide them in this way, except to deal with *Nitrochloroform* (Chloropicrin), CCl_3NO_2, and *Nitrobromoform* (Bromopicrin) in conjunction with CCl_4,CBr_4,CI_4.

The halogen atom in chloro- and bromo-mononitroparaffins can be replaced by alkyl groups by the action of zinc alkyls, whereby a homologous series of the mononitroparaffins can be built up (p. 149).

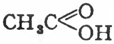
A 2. NITROSOPARAFFINS; HALOGEN-NITROSOPARAFFINS, PSEUDONITROLES; NITROLIC ACIDS

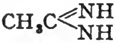
The *nitroso-group*, —NO—, gives its name to those substances which it characterizes—the *nitroso*-compounds. Primary and secondary nitrosoparaffins cannot, as a rule, be isolated (comp. B. **35**, 2323), since substances of the composition RCH_2NO and $R_2CH.NO$ possess a great tendency to transformation into *iso-nitroso*-bodies $RCH : NOH$ or *aldoximes* and *ketoximes*, $R_2C : NOH$.

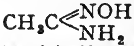
Tertiary nitrosoparaffins, on the other hand, are stable and are obtained by oxidation from β-alkyl-hydroxylamines (p. 171).

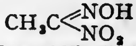
The ketoximes, $R_2C : NOH$, such as acetaldoxime, $CH_3CH : NOH$, are changed by chlorine or bromine into *chloro-* or *bromo-nitrosoparaffins*, $R_2C{<}^{Br}_{NO}$; by N_2O_4 or nitric acid into nitronitrosoparaffins, $R_2C{<}^{NO_2}_{NO}$. The latter, also known as *pseudonitroles*, are also obtained (p. 150) by the action of nitrous acid on the secondary nitro-bodies, whilst the primary compounds yield *nitrolic acids*, $RC{\leqslant}^{NO_2}_{NOH}$, under the same treatment. These substances are desmotropic, and can also be formulated as *nitrosonitronic acids*, $RC{\leqslant}^{NOOH}_{NO}$.

The nitrolic acids occupy a position after the monocarboxylic acids, into which they readily change, as well as the amidines, amidoximes, etc.:


$CH_3C{\leqslant}^{O}_{OH}$
Acetic Acid.


$CH_3C{\leqslant}^{NH}_{NH_2}$
Acetamidine.

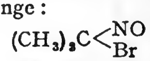

$CH_3C{\leqslant}^{NOH}_{NH_2}$
Ethenyl Amidoxime.

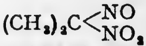

$CH_3C{\leqslant}^{NOH}_{NO_2}$
Ethenyl Nitrolic Acids.

The mesohalogen-nitrosoparaffins and the pseudonitroles take their places systematically after the ketones, from the oximes of which they can also be prepared, and into which they easily change:

$(CH_3)_2CO$
Acetone.

$(CH_3)_2C : NOH$
Acetoxime.


$(CH_3)_2C{<}^{NO}_{Br}$
Mesobromo-nitrosopropane.


$(CH_3)_2C{<}^{NO}_{NO_2}$
Propyl Pseudonitrole.

However, on account of their connection with the nitro- and nitroso-compounds these substances will be considered with them.

Nitrosoparaffins.—The direct production of these bodies from the paffins has not yet been brought about. Reduction of the nitroparaffins does not yield nitrosoparaffins, but a series of other bodies. Careful reduction gives rise first to β-alkyl hydroxylamines, Alk.NHOH, which will be examined later together with other alkyl hydroxylamine derivatives (p. 171). But the tert.-alkyl β-hydroxylamines yield nitrosoparaffins by oxidation with chromic acid (B. **31**, 457):

$$R_3C.NO_2 \longrightarrow R_3C.NHOH \longrightarrow R_3C.NO,$$

The alkylamines, possessing a tertiary alkyl group, yield tertiary-nitrosoparaffins when oxidized by permonosulphuric acid, H_2SO_5, with the intermediate formation of β-alkyl hydroxylamines:

$$R_3C.NH_2 \longrightarrow R_3C.NHOH \longrightarrow R_3C.NO.$$

Sec.-alkyl β-hydroxylamines are converted by oxidation into ketoximes or isonitrosoparaffins (p. 151), whilst the primary compounds yield hydroxamic acids (B. **36**, 701).

Nitroso-compounds are *colourless* crystalline bodies, having an odour of camphor, and are very volatile. **In the solid state they exist as double molecules,** which are dissociated by heat or solution into the intensely *blue* coloured monomolecular condition. This phenomenon can be observed in many complex nitroso-bodies (B. **35**, 3090). Sunlight retards this dissociation (comp. p. 61). Nitroso-bodies on oxidation yield nitro-compounds.

Nitroso-tert.-butane, $(CH_3)_3C.NO$, m.p. 76°, melts in a closed capillary tube to a blue liquid, which, on solidification, forms colourless crystals. *Nitroso-tert.-pentane*, $C_2H_5C(CH_3)_2NO$, m.p. 50°, is prepared by the oxidation of tert.-butyl and amylamine. *Nitrosooctane*, $(CH_3)_2CHCH_2CH_2C(CH_3)_2NO$, m.p. 54°, results from the reduction of nitrooctane.

meso-*Halogen-nitrosoparaffins* are prepared by the action of chlorine and sodium hydroxide (C. 1906, I. 1692), or of bromine and pyridine (B. **35**, 3092) on ketoximes (see above, p. 151):

$$(CH_3)_2C{<}^{NO}_{Cl} \xleftarrow{Cl} (CH_3)_2C{=}NOH \xrightarrow{Br} (CH_3)_3{<}^{NO}_{Br}.$$

They are *blue*, very volatile bodies, of a sharp odour, and are easily decomposed. Oxidation changes them into halogen-nitro-bodies (p. 151); with silver nitrite they give rise to the psuedonitroles (see below).

meso-*Chloronitrosopropane*, $(CH_3)_2CCl.NO$, b.p.$_{18}$ 7°, is formed from $(CH_3)_2$-CNOH and NaClO. An excess of the latter forms chloronitropropane (p. 151). *Bromonitrosopropane*, b.p.$_{181}$ 41·5°. *Bromonitrosobutane*, $C_2H_5C(CH_3)Br.NO$, b.p.$_{15}$ 28°. *Bromonitrosodimethyl Butane*, $(CH_3)_3C.C(CH_3)Br.NO$, m.p. 120°, with decomposition, form sky-blue crystals which can be sublimed.

1,1-*Chloronitrosoethane*, $CH_3CHCl.NO$, m.p. 65°, is prepared in a hydrochloric acid solution from acetaldoxime, $CH_3CH : NOH$, and chlorine. It changes on fusion from colourless (dimolecular) plates, to a blue (monomolecular) liquid. This soon becomes colourless, owing to an isomeric change to acetohydroxamyl chloride (*q.v.*) which yields 1,1,1-*Dichloronitrosoethane*, $CH_3.CCl_2.NO$, a blue-coloured oil, b.p. 68°, by the further action of chlorine (B. **35**, 3113).

Pseudonitroles or meso-**Nitronitrosoparaffins.** As already described, the pseudonitroles are prepared:

(1) By the action of nitrous acid on sec.-nitroparaffins (p. 151):

$$(CH_3)_2CH.(NO_2)+NO.OH=(CH_3)_2C{<}^{NO_2}_{NO}+H_2O.$$

(2) From meso-halogen-nitrosoparaffins and silver nitrite:

$$(CH_3)_2C{<}^{Br}_{NO}+AgNO_2=(CH_3)_2C{<}^{NO_2}_{NO}+AgBr$$

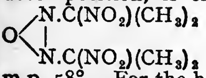
a method indicating its nitronitrosoparaffin constitution (B. **35**, 3093).

(3) By the action of N_2O_4 on the ketoximes (see above, halogen-nitrosoparaffins), which is the simplest method of preparation (B. **34**, 1911):

$$4(CH_3)_2C : NOH+3N_2O_4=4(CH_3)_2C{<}^{NO_2}_{NO}+2H_2O+2NO.$$

The pseudonitroles are pungent, colourless crystalline substances, dimolecular when in the solid state. On melting or solution they change into the deep blue monomolecular form (B. **35**, 3094). They possess a neutral reaction, and are insoluble in water, alkalies, and acids. Chromic acid oxidizes them in glacial acetic acid solution to *Dinitro-bodies*. Reduction with hydroxylamine in alkaline solution changes the pseudonitroles into ketoximes (B. **29**, 88, 98).

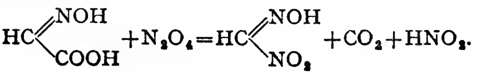
Propyl Pseudonitrole, Nitronitrosopropane, $(CH_3)_2C(NO_2)NO$, m.p. 76°, with decomposition, is changed by NH_2OH into *Tetramethyl Dinitroazoxymethane*,



$$O{<}\begin{matrix}N.C(NO_2)(CH_3)_2\\ |\\ N.C(NO_2)(CH_3)_2\end{matrix}$$

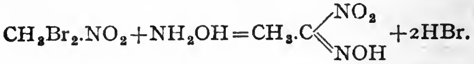
(B. **34**, 1913), *Butyl Pseudonitrole*, 2,2-*Nitronitrosobutane*, m.p. 58°. For the higher homologues, see B. **29**, 94; **35**, 3095.

Nitrolic Acids.—As has already been described (p. 151), the nitrolic acids result from (1) the action of nitrous acid at the moment of its formation on the primary mononitro-compounds. (2) A more direct reaction is that of *a*-isonitrosocarboxylic acids with N_2O_4, during which CO_2 is eliminated (C. 1903, II. 937):



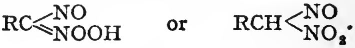
$$HC{<}^{NOH}_{COOH}+N_2O_4=HC{<}^{NOH}_{NO_2}+CO_2+HNO_2.$$

(3) They can also be obtained from dibromomononitroparaffins and hydroxylamine:



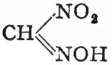
$$CH_3Br_2.NO_2+NH_2OH=CH_3.C\begin{cases}NO_2\\NOH\end{cases}+2HBr.$$

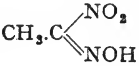
Thus, they are to be considered as being nitro-oximes, but may be desmotropically connected with the nitronitroso-bodies:



$$RC\begin{cases}NO\\NOOH\end{cases}\quad\text{or}\quad RCH\begin{cases}NO\\NO_2\end{cases}.$$

The nitrolic acids are solid, crystalline, colourless, or faintly-yellow coloured bodies, soluble in water, alcohol, ether, and chloroform. They are weak acids, and form very explosive salts with alkalis, yielding at the same time a *dark-red colour*. The erythronitrolic acid salts are changed by the action of sunlight and of heat to the colourless leuco-nitrolic acid salts (B. **31**, 2854). They are decomposed into hydroxylamine and the corresponding fatty acids by tin and hydrochloric acid. When heated with dilute sulphuric acid they split up into oxides of nitrogen and *fatty acids*. They are converted into esters when treated with acid chlorides (B. **27**, 1600; **29**, 1218). For further reactions, see the derivatives of the fatty acids.

Methyl Nitrolic Acid,  $CH\begin{cases}NO_2\\NOH\end{cases}$, m.p. 68° with decomposition.

Ethyl Nitrolic Acid,  $CH_3.C\begin{cases}NO_2\\NOH\end{cases}$, m.p. 88° with decomposition.

Propyl Nitrolic Acid,  $CH_3.CH_2.C\begin{cases}NO_2\\NOH\end{cases}$, m.p. 60° with decomposition.

Appendix. *Nitroalkylisonitramines*, such as *nitroethylisonitramine*, $CH_3CH(NO_2)N_2O_2H$, result from the passage of NO into an alcoholic solution of an aliphatic mononitro-body, with the addition of sodium ethoxide (A. **300**, 106).

Diisonitramines, such as *Methylene Diisonitramine*, $CH_2(N_2O_2H)_2$, result from the action of NO, in the presence of sodium ethoxide, on an alcoholic solution of a ketone which contains the CO group attached to a methyl or methylene group (A. **300**, 81).

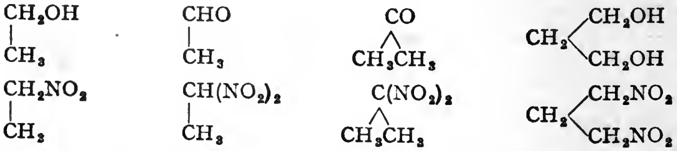
A 3. **Dinitroparaffins.**—There are three classes of dinitroparaffins; the two nitro-groups may be joined—

(1) to one terminal carbon atom: *ω_2-dinitroparaffins* or primary dinitro-compounds;

(2) to an intermediate carbon atom: *mesodinitroparaffins* or secondary dinitro-compounds;

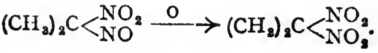
(3) to two different carbon atoms.

These three classes, according to the position of the groups, bear the same relations to aldehydes, ketones, and glycols as do the mononitroparaffins to the alcohols:



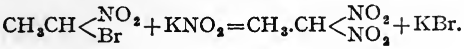
Notwithstanding these points of relationship, it is practicable to discuss the dinitroparaffins after the bromonitro- and nitrosonitro-bodies (pseudonitroles).

Formation.—(1) By the oxidation of the pseudonitroles with chromic acid *mesodinitroparaffins* are produced:



$$(CH_3)_2C\begin{cases}NO_2\\NO\end{cases}\xrightarrow{O}(CH_3)_2C\begin{cases}NO_2\\NO_2\end{cases}.$$

(2) They result from the interaction of potassium nitrite and the bromonitroparaffins:



$$CH_3CH{<}{}^{NO_2}_{Br} + KNO_2 = CH_3.CH{<}{}^{NO_2}_{NO_2} + KBr.$$

(3) By the action of concentrated nitric acid on
   (*a*) secondary alcohols,
   (*b*) ketones,
   (*c*) mono-alkylized acetoacetic esters,
the carbon chain is torn asunder and *ω_2-dinitroparaffins* are formed (C. 1901, II. 334):

$$\begin{array}{rcl} (C_2H_5)_2CHOH & \longrightarrow & CH_3.CH(NO_2)_2 \\ (C_2H_5)_2CO & \longrightarrow & CH_3.CH(NO_2)_2 \\ CH_3CO.CH(C_2H_5)CO_2C_2H_5 & \longrightarrow & CH_3.CH_2.CH(NO_2)_2. \end{array}$$

The action of iodoalkyls on the salts of the primary dinitroparaffins results in the production of mesodinitroparaffins (comp. A. **280**, 282).

(4) By the oxidation of saturated monocarboxylic acids, containing a tertiary carbon atom, with nitric acid: isobutyric and isovaleric acids yield *mesodinitropropane*:

$$\overrightarrow{(CH_3)_2CHCO_2H \qquad (CH_3)_2CH.CH_2.CO_2H \longrightarrow} (CH_3)_2C(NO_2)_2.$$

The primary dinitro-bodies are acids in which the group $CH(NO_2)_2$ changes into $C(NO_2):NOOH$. The primary and secondary classes lose hydroxylamine when they are reduced with tin and hydrochloric acid. The former yield, at the same time, monocarboxylic acids, and the latter ketones (B. **23**, 3494).

Dinitromethane, $CH_2(NO_2)_2$, is a colourless volatile oil (B. **32**, 624). 1,1-*Dinitroethane*, $CH_3CH(NO_2)_2$, b.p. 185–186° (formation, comp. p. 156, Trinitroethane), 1,1-*Dinitropropane*, $CH_3CH_2CH(NO_2)_2$, b.p. 189°; 1,1-*Dinitrohexane*, b.p. 212°; 2,2-*Dinitropropane*, $CH_3C(NO_2)_2CH_3$, m.p. 53°, b.p. 185·5°; 2,2-*Dinitrobutane*, $CH_3CH_2C(NO_2)_2.CH_3$, b.p. 199°. For higher homologues, see B. **29**, 95. Di-tert.-1,2-dinitroparaffins are obtained by the action of finely divided silver on the mesobromonitroparaffins (p. 152):

$$2R_2C(NO_2)Br + 2Ag = R_2C(NO_2).C(NO_2)R_2 + 2AgBr.$$

Tetramethyl-1,2-*dinitroethane*, $(CH_3)_2C(NO_2).C(NO_2)(CH_3)_2$, m.p. 211°, can be obtained by heating diisopropyl with dilute nitric acid (comp. also p. 148); and by electrolysis of the potassium salt of sec.-nitropropane. *Dimethyldiethyl*-1, 2-*dinitroethane*, m.p. 80°, is prepared from 2,2-bromonitrobutane (C. 1907, I. 230). 1,3-*Dinitropropane*, $NO_2CH_2CH_2CH_2NO_2$, is obtained as an unstable oil from trimethylene iodide and silver nitrate. 1,4-*Dinitrodiisobutyl*, $NO_2C(CH_3)_2CH_2CH_2C(CH_3)_2NO_2$, m.p. 125°, is prepared from diisobutyl by heating it with dilute nitric acid. 1,6-*Dinitrodiisoamyl*, $(CH_3)_2C(NO_2)[CH_2]_4C(NO_2)(CH_3)_2$, m.p. 102°, is similarly prepared (B. **25**, 2638; **28**, 1858; C. 1906, II. 312 *et seq.*). These dinitroparaffins yield the corresponding *diamines* when reduced.

Polynitroparaffins. *Trinitromethane, Nitroform*, $CH(NO_2)_3$, m.p. 15°, was first prepared by the action of water on trinitroacetonitrile, which gave at the same time CO_2 and ammonium isonitroform. It is also prepared from tetranitromethane by the action of alcoholic potassium hydroxide or ammonia with the simultaneous production of ethyl nitrate:

$$\begin{array}{rcl} C(NO_2)_3.CN + 2H_2O & = & (NO_2)_2C{=}NOONH_4 + CO_2. \\ C(NO_2)_4 + C_2H_5OK & = & (NO_2)_2C{=}NOOK + C_2H_5O.NO_2. \end{array}$$

It also results from the interaction of acetylene (p. 88) and nitric acid.

It forms colourless crystals, dissolving to a colourless solution in non-aqueous solvents, but turning yellow in water. The salts are also of a yellow colour, and are probably derived from isonitroform $(NO_2)_2C{=}NOOH$ (p. 150). In non-dissociating solvents a colourless mercury salt, $(NO_2)_3C.\frac{1}{2}Hg$, is formed, but in dissociating liquids this exists as $(NO_2)_2C{=}NOO.\frac{1}{2}Hg$ (B. **38**, 973). Thus, in water it assumes the iso- or *aci*- condition, and is a very strong mono-basic acid.

Free trinitromethene is volatile in steam, and explodes violently on heating. The freshly prepared potassium salt explodes at 97–99°, and spontaneously decomposes, on keeping, in dry air. The ammonium compound crystallizes in yellow needles, and explodes mildly at 200°. The silver salt dissolves easily in water and in alcohol (B. **32**, 628).

Trinitroethane, $CH_3C(NO_2)_3$, m.p. 56°, is obtained from the silver compound of trinitromethane and iodomethane; and also from methylmalonic acid and nitric acid. It is insoluble in water. Potassium hydroxide solution changes it into potassium dinitroethane, whilst potassium methoxide produces dinitroethyl methyl ether, $CH_3OCH_2CH(NO_2)_2$ (B. **36**, 434).

Bromonitroform, Bromotrinitromethane, $C(NO_2)_3Br$, m.p. 12°, is produced when bromine and nitroform remain in contact for some days in the sunlight. A quicker method is to pass bromine into an aqueous solution of the mercury salt of nitroform. It is volatile in steam without decomposition.

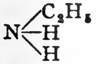
Tetranitromethane, $C(NO_2)_4$, m.p. 13°, b.p. 126°, $D._4^{13}=1{\cdot}65$, is obtained from diacetyl orthonitric acid and acetic anhydride (B. **36**, 2225); also by warming nitroform with a mixture of fuming nitric acid and sulphuric acid. It is a colourless oil; insoluble in water, but easily soluble in alcohol and ether. It is very stable and distils without exploding. For its transformation into trinitromethane, see above.

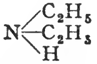
Tetranitroethane is obtained as a dipotassium salt, $KOON:C(NO_2).C(NO_2):NOOK$, from bromopicrin, CBr_3NO_2, and potassium cyanide. It is decomposed by cold dilute sulphuric acid, forming dinitromethane (B. **35**, 4288).

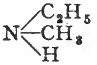
B. ALKYLAMINES AND ALKYL AMMONIUM DERIVATIVES

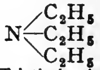
Alkylamines are substances formed by replacement of the hydrogen atoms in ammonia by alkyl groups.

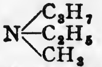
According as one, two, and three atoms are substituted, there result the *primary*, *secondary*, and *tertiary* amines:


Ethylamine.


Diethylamine.


Methyl Ethylamine.


Triethylamine.


Methyl Ethyl-Propylamine.

These are also sometimes called amide, imide, and nitrile bases. Among the secondary and tertiary amines, may be distinguished *simple* amines, those with similar alcohol radicals, and *mixed* amines, those containing different alcohol radicals (comp. *simple* and *mixed* ethers, p. 125). Derivatives also exist which correspond with the ammonium salts and hypothetical ammonium hydroxide, NH_4OH:

$(C_2H_5)_4\overset{v}{N}Cl.$
Tetraethyl Ammonium Chloride.

$(C_2H_5)_4\overset{v}{N}.OH.$
Tetraethyl Ammonium Hydroxide.

known as the quaternary alkyl ammonium compounds. It must be noticed that the words "primary," "secondary," and "tertiary" when applied to alcohols (p. 101) carry different meanings than when employed with amines, where they indicate the number of alkyl-substituted hydrogen atoms in an NH_3-group. When considering the close connection between alcohols and amines (comp. pp. 104, 163), this might lead to confusion.

Isomerism of the Alkylamines.—The isomerism of the simple alkylamines depends on the homology of the alcohol radicles, ***metamerism***; and in the higher alkylamines, in addition, on the different position of the nitrogen in the same carbon chain, *isomerism of position;* and also on the different manner of linkage of the carbon atoms of the isomeric alkyl residues, *nucleus isomerism* (p. 25).

There are eight known isomers of $C_4H_{11}N$:

$$N\left\{\begin{array}{l}C_4H_9\\H\\H\end{array}\right. \qquad N\left\{\begin{array}{l}C_3H_7\\CH_3\\H\end{array}\right. \qquad N\left\{\begin{array}{l}C_2H_5\\C_2H_5\\H\end{array}\right. \qquad N\left\{\begin{array}{l}C_2H_5\\CH_3.\\CH_3\end{array}\right.$$

4 Isomeric Butylamines. 2 Isomeric Propyl Methylamines. Diethylamine. Ethyl Dimethylamine.

History.—The existence of alkylamines, or alcohol bases, was very definitely predicted by *Liebig* in 1842 (Hdw. **1**, 689). In 1849 *Würtz* discovered a method for the preparation of *primary amines*, which consisted in decomposing isocyanic ester with aqueous potassium hydroxide. This was a discovery of the greatest importance for the development of organic chemistry. Shortly afterwards, in 1849, *A. W. Hofmann*, by the action of alkylogens on ammonia, discovered a reaction which made possible the preparation of all the classes described in the preceding paragraphs: *primary, secondary, tertiary amines*, and the *alkyl ammonium bases.* This afforded the experimental basis for the introduction of the *ammonia type* into organic chemistry (comp. p. 19). Since that time numerous other methods have been found, particularly for the primary amines.

The following general methods are the most important for preparing the above compounds:

(1*a*) The iodides, the bromides, or the chlorides of the alcohol radicals are heated to 100°, in sealed tubes, with alcoholic ammonia (*A. W. Hofmann*, 1849). Two reactions occur here: first, the alkylogens combine with the ammonia, forming alkyl ammonium salts, which are then partially decomposed by *excess* of ammonia into alkylamines, to which alkylogens again unite themselves—*e.g.*:

$$\begin{array}{l}NH_3+C_2H_5I=NH_2(C_2H_5)HI \xrightarrow{NH_3} NH_2C_2H_5 \; +NH_4I.\\ NH_2C_2H_5+C_2H_5I=NH(C_2H_5)_2HI \xrightarrow{NH_3} NH(C_2H_5)_2+NH_4I.\\ NH(C_2H_5)_2+C_2H_5I=N(C_2H_5)_3HI \xrightarrow{NH_3} N(C_2H_5)_3 \; +NH_4I.\\ N(C_2H_5)_3+C_2H_5I=N(C_2H_5)_4I.\end{array}$$

The final product consists of the hydroiodides of primary, secondary, and tertiary amines, *i.e.* the amide, imide, and nitrile bases, as well as the quaternary ammonium compounds. The amines are best obtained on a large scale by the action of ammonia on the alkyl bromides (B. **22,** 700).

Potassium and sodium hydroxides decompose the salts of the amine, imide, and nitrile bases, with the liberation of the free bases, whereas the quaternary tetra-alkyl ammonium salts are *not* decomposed by alkali hydroxide, and can thus be easily separated from the primary, secondary, and tertiary amines (B. **20,** 2224).

It is remarkable that the primary and secondary alkyl iodides yield amines, whilst the tertiary alkyl iodides split off hydrogen iodide and pass into olefines. On the further alkylation of primary and secondary amines by means of bromoalkyls, see B. **38**, 1539.

(1*b*) The *esters of nitric acid*, when heated to 100° with alcoholic ammonia, react in a manner analogous to the iodoalkyls:

$$C_2H_5.O.NO_2+NH_3=C_2H_5.NH_2+HNO_3.$$

This reaction is often very convenient for the preparation of the primary amines (B. **14**, 421).

(1*c*) *Tertiary amines* are produced when primary and secondary bases are heated with an excess of potassium methyl sulphate (B. **24**, 1678):

$$(C_2H_5)_2NH+CH_3OSO_3K=(C_2H_5)_2NCH_3+HOSO_3K.$$

(1*d*) Mono-, di-, and tri-alkylamines are obtained by directly heating the alcohols to 250–260° with zinc-ammonium chloride, $ZnCl_2.NH_3$ (B. **17**, 640).

(1*e*) The methylation of ammonia and amines can easily be carried out by means of two reagents—dimethyl sulphate (p. 138) and formaldehyde (p. 197) (comp. B. **38**, 880; A. **327**, 104; C. 1906, II. 1716), *e.g.*—

$$NH_3+(CH_3)_2SO_4 \xrightarrow{0^\circ} NH_2.CH_3+H(CH_3)SO_4.$$
$$2NH_4Cl+9CH_2O \xrightarrow{120^\circ} 2N(CH_3)_3.HCl+3CO_2+3H_2O.$$

(2) They are also formed by the action of nascent hydrogen (HCl and Zn) on the nitro-paraffins (p. 150), when the alkyl hydroxylamines appear as *intermediate* products; also on the halogen mono-nitro-paraffins:

$$CH_3NO_2+\ 4\dot{H}=CH_3NHOH+H_2O.$$
$$CH_3.NO_2+\ 6H=CH_3.NH_2\ \ +2H_2O.$$
$$CCl_3NO_2+12H=CH_3NH_2\ \ +2H_2O+3HCl.$$

This method is particularly important in the manufacture of commercially valuable primary amines—*e.g.* aniline, $C_6H_5NH_2$—from the readily accessible aromatic nitro-bodies. *Zinin* discovered the method when investigating the reduction of nitrobenzene, $C_6H_5NO_2$, and *V. Meyer* applied it to the aliphatic nitro-derivatives.

(3*a*) By the action of sodium in absolute alcohol on the *aldehyde-alkylimides* (B. **29**, 2110); (3*b*) when zinc dust and hydrochloric acid are allowed to act on aldehyde-ammonia derivatives (B. **27**, R. 437); (3*c*) from the *phenylhydrazones* (*Tafel*), and (3*d*) the *oximes* (*Goldschmidt*) of the aldehydes and ketones by means of sodium amalgam and glacial acetic acid (B. **19**, 1925, 3232; **20**, 505; **22**, 1854):

$$(CH_3)_2CH.CH=N(CH_3)\ \ +2H=(CH_3)_2CH.CH_2.NHCH_3.$$
$$(CH_3).CH:N—NH.C_6H_5+4H=CH_3.CH_2NH_2\ \ +C_6H_5NH_2.$$
$$(CH_3)_2C:N—NH.C_6H_5\ \ +4H=(CH_3)_2CHNH_2+C_6H_5NH_2.$$
$$(CH_3)_2C:N—OH\ \ +4H=(CH_3)_2CHNH_2+H_2O.$$

Reaction 3*a* yields secondary amines, whilst 3*b*, 3*c*, and 3*d* give rise to primary amines, together with some secondary and tertiary amines. The above reactions can be carried out with molecular hydrogen in presence of finely divided nickel or copper (C. 1905, II. 540); also by electrolytic hydrogen in acid solution (C. 1906, II. 1539).

(3*e*) Connected with these latter methods of formation is that of primary amines, accompanied by secondary and tertiary, from aldehydes and ketones by ammonium formate (A. **343**, 54):

$$(C_2H_5)_2C=O+HCO_2NH_4=(C_2H_5)_2CH.NH_2+CO_2+H_2O.$$

(4) The reduction of acid amides with hydrogen from boiling amyl alcohol and sodium (C. 1899, II. 703) gives a primary amine:

$$\underset{\text{Acetamide.}}{CH_3CONH_2}+4H=H_2O+\underset{\text{Ethylamine.}}{CH_3CH_2NH_2}$$

(5) By the action of nascent hydrogen (from alcohol and sodium, B. **18**, 2957; **19**, 783; **22**, 1854) on the *nitriles* or *alkyl cyanides* (*Mendius*, A. **121**, 129):

$$HCN+4H=\underset{\text{Methylamine.}}{CH_3NH_2};\ \underset{\text{Acetonitrile.}}{CH_3.CN}+4H=\underset{\text{Ethylamine.}}{CH_3.CH_2.NH_2}.$$

This reaction constitutes an important intermediate factor in the synthesis of both alcohols (p. 105) and amines.

(6) If the isocyanides of the alkyls, the isonitriles, or carbylamines are heated with dilute hydrochloric acid, formic acid is set free (*A. W. Hofmann*):

$$C_2H_5.NC+2H_2O=C_2H_5.NH_2+CH_2O_2.$$

(7*a*) The esters of *isocyanic* or *isocyanuric acid* may be distilled with potassium hydroxide (*Wurtz*, 1848):

$$CO:N.CH_3+2KOH=NH_2.CH_3+K_2CO_3.$$

Cyanic acid is changed to ammonia in precisely the same manner:

$$CO:NH+2KOH=NH_3+K_2CO_3.$$

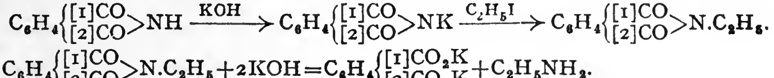
To convert alcohol radicals into corresponding amines, the iodides are heated together with silver cyanate; the product of the reaction is then mixed with powdered sodium hydroxide, and distilled in an oil bath (B. **10**, 131).

(7*b*) The *isothiocyanic esters* or the *mustard oils*, etc., are also broken down into primary amines when heated with water or dilute acids:

$$CS:N.C_2H_5+2H_2O=CO_2+H_2S+C_2H_5NH_2.$$

The isocyanic esters and the isothiocyanic esters or mustard oils are alkyl derivatives of the imide of carbonic acid, and thiocarbonic acid.

(7*c*) The alkyl compounds of the *imide* of *o-phthalic acid* (*q.v.*) have been found to be well adapted for the preparation of primary amines. They are readily prepared by acting on potassium phthalimide with alkyl iodides; and, when heated with potassium hydroxide or acids, they separate into phthalic acid and primary amines (*Gabriel*, **20**, 2224; **24**, 3104):

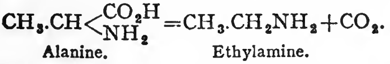


$$C_6H_4\left\{\begin{array}{l}[1]CO\\ {[2]CO}\end{array}\right\rangle NH \xrightarrow{KOH} C_6H_4\left\{\begin{array}{l}[1]CO\\ {[2]CO}\end{array}\right\rangle NK \xrightarrow{C_2H_5I} C_6H_4\left\{\begin{array}{l}[1]CO\\ {[2]CO}\end{array}\right\rangle N.C_2H_5.$$

$$C_6H_4\left\{\begin{array}{l}[1]CO\\ {[2]CO}\end{array}\right\rangle N.C_2H_5+2KOH=C_6H_4\left\{\begin{array}{l}[1]CO_2K\\ {[2]CO_2K}\end{array}\right.+C_2H_5NH_2.$$

(7*d*) Secondary amines result, together with benzene sulphochloride, from the breaking down of a molecule of dialkylamine sulphonic acid, which is obtained from chlorosulphonic acid and benzene sulphonic dialkylamide, $C_6H_5SO_2NR_2$ (C. 1900, I. 524).

(8) By the distillation of amino-carboxylic acids, especially with barium hydroxide:



$$CH_3.CH\left\langle\begin{array}{l}CO_2H\\ NH_2\end{array}\right.=CH_3.CH_2NH_2+CO_2.$$

Alanine. Ethylamine.

(9) The decomposition of the secondary and tertiary aromatic p-nitrosamines into salts of *nitrosophenol* (*q.v.*), by means of potassium hydroxide, affords a means of preparing primary and secondary amines; p-nitrosodimethylaniline yields dimethylamine:

$$NO[4]C_6H_4[1]N(CH_3)_2+KOH=NH(CH_3)_2+NO[4]C_6H_4[1]OK.$$

(10) The conversion of the amides of the monocarboxylic acids into amines containing an atom less of carbon (*A. W. Hofmann*, B. **18**, 2734; **19**, 1822), can be effected by means of potassium hydroxide and bromine.

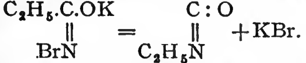
This reaction constitutes an intermediate step in the decomposition of the saturated monocarboxylic acids, because the primary amines can be changed to alcohols, and the latter be oxidized to carboxylic acids, containing an atom less of carbon than the fatty acids, whose amides constituted the parent substance.

The reaction proceeds in four stages. The first is the formation of the "bromamide" of the fatty acid, which, in the second stage, forms a salt with potassium hydroxide; in the third, Br splits off and atomic rearrangement leads to the formation of an alkyl isocyanate, which, lastly, is broken down by excess of alkali into the primary amine and potassium carbonate (B. **35**, 3579; J. pr. Ch. [2] **73**, 228; C. 1903, I. 489):

I. $C_2H_5CONH_2+Br_2+KOH=C_2H_5CONHBr+KBr+H_2O.$

II. $C_2H_5CONHBr+KOH=C_2H_5(OK):NBr+H_2O.$

III.



$$\begin{array}{c}C_2H_5.C.OK\\ \|\\ BrN\end{array}=\begin{array}{c}C:O\\ \|\\ C_2H_5N\end{array}+KBr.$$

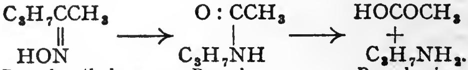
IV. $C_2H_5NCO+2KOH=C_2H_5NH_2+K_2CO_3.$

The bromamide and the alkyl isocyanate can both be isolated under special conditions.

If one molecule of bromine acts on two of the amide, ***compound ureas*** (*q.v.*) are formed—acetamide yields acetyl monomethyl urea.

The amides of the fatty acids containing more than 5 C-atoms yield at the same time an increasing quantity of the nitrile of the next lower acid, *e.g.* $C_8H_{17}CONH_2$ gives $C_7H_{15}.CN$. If, however, the higher bromamide or chloramide is converted by sodium methoxide into the corresponding urethane and the latter is hydrolysed, a good yield of the higher primary amine is obtained (B. **30**, 898; C. 1899, II. 363).

(10*a*) The above described *Hofmann* rearrangement of the bromamide is very similar to the *Beckmann* rearrangement of ketoximes (p. 227), from which primary amines can also be obtained:



$$\begin{matrix} C_3H_7CCH_3 \\ \| \\ HON \end{matrix} \longrightarrow \begin{matrix} O:CCH_3 \\ | \\ C_3H_7NH \end{matrix} \longrightarrow \begin{matrix} HOCOCH_3 \\ + \\ C_3H_7NH_2. \end{matrix}$$

Propyl methyl Ketoxime. Propyl Acetamide. Propylamine.

Another related reaction is the transformation of hydroxamic acids (compare Benzhydroxamic acid, Vol. II.). Similar, too, is (10*b*) the formation of primary amines from acid-azides and alcohol. The corresponding acid is converted into its ester, the ethoxy-group is then replaced with $(NH.NH_2)$ by means of hydrazine hydrate, the acid-azide, $R.CO.NH.NH_2$, is changed by nitrous acid into the azide $R.CO.N_3$, which is boiled with water or alcohol, and the resulting urea or urethane acted on with concentrated hydrochloric acid, when the alkylized base is liberated (*Curtius*, B. **27**, 779; **29**, 1166).

$$R.CO.N_3 \xrightarrow{C_2H_5OH} R.NH.CO.OC_2H_5 \xrightarrow{HCl} R.NH_2.$$

Properties and Reactions of the Amines.—The amines are very similar to ammonia in their behaviour. The lower members are gases, possessing an ammoniacal odour, and are very readily soluble in water. Their combustibility distinguishes them from ammonia, a property to which *Würtz* drew attention in connection with ethylamine (B. **20**, R. 928). The higher members are liquids, readily soluble in water, and only the highest dissolve with difficulty. Many amines possess the power of forming hydrates with water, accompanied by very considerable rise in temperature. They can be dried over potassium carbonate. Most of the oily hydrates contain one molecule of water for each nitrogen atom. This can only be removed by means of potassium hydroxide (B. **27**, R. 579), or by distillation over barium oxide. Like ammonia, they unite directly with acids to form salts, which differ from ammoniacal salts by their solubility in alcohol. They combine with some metallic chlorides, and form compounds perfectly analogous to the ammonium double salts; *e.g.*:

$$[N(CH_3)H_3Cl]_2PtCl_4. \qquad N(CH_3)H_3Cl.AuCl_3. \qquad [N(CH_3)_2HCl]_2HgCl_2.$$

The ammonia in the alums, the cuprammonium salts and other compounds may be replaced by amines.

Their basicity is greater than that of ammonia, and increases with the number of alkyls introduced (J. pr. Ch. [2] **33**, 352; A. **345**, 256).

The reactivity of the primary and secondary amines, as compared with the tertiary amines, is dependent on the ease with which the ammonia hydrogen atoms, not substituted by alcohol radicals, are replaced; hence, the primary and the secondary amines in many reactions behave like ammonia.

A primary amine is distinguished from a secondary amine, and this from a tertiary amine, by treating the amine alternately with iodomethane and potassium hydroxide until all the hydrogen atoms in the ammonia present are replaced by methyl groups. Whether the latter have entered, and what their number may be, is most conveniently determined by the analysis of the platinum double chloride of the base previous to and after the action of the iodomethane. If two methyl groups have entered, then the amine was primary; if one methyl group has entered, then the base was secondary; and should the base remain unchanged, then it is tertiary in its character.

Tertiary, secondary, and primary amines may also be obtained by the dry distillation of the halogen salts of the ammonium bases, such as methyl-ammonium hydrochloride:

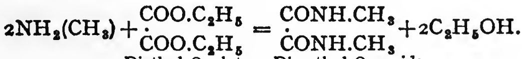
$$\begin{array}{ll} N(CH_3)_4Cl & = N(CH_3)_3 + CH_3Cl \\ N(CH_3)_3HCl & = NH(CH_3)_2 + CH_3Cl \\ NH(CH_3)_2HCl & = NH_2(CH_3) + CH_3Cl, \text{ etc.} \end{array}$$

These reactions serve for the commercial production of methyl chloride (p. 135) from trimethylamine.

Primary and secondary amines show the following reactions:

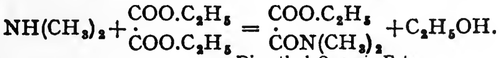
(1) Primary and secondary amines, like ammonia, react with acid esters, forming mono- and di-alkylized acid amides (*q.v.*) and alcohols. *A. W. Hofmann* based a method for the separation of primary, secondary, and tertiary amines upon their behaviour towards diethyl oxalate (B. **8**, 760).

The mixture of the dry bases is treated with diethyl oxalate, when the primary amine, *e.g.*, methylamine, is changed to diethyloxamide, which is soluble in water, dimethylamine is converted into the ester of dimethyl oxamic acid (see oxalic acid compounds), and trimethylamine is not acted on:



$$2NH_2(CH_3)+\begin{array}{l}COO.C_2H_5\\ COO.C_2H_5\end{array}=\begin{array}{l}CONH.CH_3\\ CONH.CH_3\end{array}+2C_2H_5OH.$$

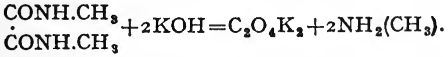
Diethyl Oxalate. Dimethyl Oxamide.



$$NH(CH_3)_2+\begin{array}{l}COO.C_2H_5\\ COO.C_2H_5\end{array}=\begin{array}{l}COO.C_2H_5\\ CON(CH_3)_2\end{array}+C_2H_5OH.$$

Dimethyl Oxamic Ester.

When the reaction-product is distilled, the unaltered trimethylamine passes over. Water will extract the dimethyloxamide from the residue; on distillation with potassium hydroxide it changes into *methylamine* and potassium oxalate:



$$\begin{array}{l}CONH.CH_3\\ CONH.CH_3\end{array}+2KOH=C_2O_4K_2+2NH_2(CH_3).$$

The insoluble dimethyl oxamic ester is converted, by distillation with potassium hydroxide, into *dimethylamine*:

$$\begin{array}{l}COO.C_2H_5\\ CON(CH_3)_2\end{array}+2KOH=C_2O_4K_2+NH(CH_3)_2+C_2H_5.OH.$$

The behaviour of the primary and secondary amines towards formaldehyde can be utilized for their separation from one another (B. **29**, R. 520).

(2*a*) The secondary aliphatic amines, *e.g.* diethylamine (also piperidine), are readily acted on by a series of non-metallic chlorides, non-metallic oxy- and sulpho-chlorides, as well as chlorides of inorganic acids. The dialkylamine residue replaces one or all of the chlorine atoms. The products are dialkylized acid amides (B. **29**, 710).

Thionyl chloride replaces both the hydrogen atoms in primary amines by the thionyl residue, with the production of *thionylamines*, the alkylized imides of sulphurous acid (*Michaelis*), which bear the same relation to sulphur dioxide that the isocyanic esters do to carbon dioxide.

Nitrosyl chloride, NOCl, and nitrosyl bromide, NOBr, produce from primary amines *alkyl chlorides* and *bromides*, with the formation of water and nitrogen; under similar treatment secondary amines yield nitrosamines (C. 1898, II. 887; B. **40**, 1052).

The following arrangement, taking diethylamine as example, affords a review of these reactions:

$\begin{array}{l}SCl\\ \dot{S}Cl\end{array}$	$\longrightarrow$	$\begin{array}{l}S—N(C_2H_5)_2\\ \dot{S}—N(C_2H_5)_2\end{array}$	Dithio-diethylamine.
SCl_2	$\longrightarrow$	$S{<}{N(C_2H_5)_2 \atop N(C_2H_5)_2}$	Monothio-diethylamine.
$SOCl_2$	$\longrightarrow$	$SON(C_2H_5)$	Thionyl-ethylamine.
	$\longrightarrow$	$SO{<}{N(C_2H_5)_2 \atop N(C_2H_5)_2}$	Thionyl-diethylamine.
SO_2Cl_2	$\longrightarrow$	$SO_2{<}{N(C_2H_5)_2 \atop N(C_2H_5)_2}$	Sulphuryl- or Sulpho-diethylamine.
$NOCl$	$\longrightarrow$	$NO.N(C_2H_5)_2$	Nitroso-diethylamine.
PCl_3	$\longrightarrow$	$PCl_2N(C_2H_5)_2$	Diethylamine-chlorophosphine.
$POCl_3$	$\longrightarrow$	$POCl_2N(C_2H_5)_2$	Diethylamine-oxychlorophosphine.
	$\longrightarrow$	$PO[N(C_2H_5)_2]_3$	Tridiethylamine-phosphine-oxide.
$PSCl_3$	$\longrightarrow$	$PSCl_2N(C_2H_5)_2$	Diethylamine-sulphochlorphosphine.
BCl_3	$\longrightarrow$	$BCl_2N(C_2H_5)_2$	Diethylamine-chloroboride.
$SiCl_4$	$\longrightarrow$	$SiCl_3N(C_2H_5)_2$	Diethylamine-chlorosilicide.

(2*b*) Primary and secondary amines behave like ammonia towards organic acid chlorides—*e.g.* acetyl chloride—forming mono- and dialkyl acid amides.

The reaction proceeds twice as fast in the case of the primary amines as in that of the secondary.

Primary, secondary, and tertiary bases can be separated from each other by means of benzene sulphochloride, $C_6H_5.SO_2Cl$. In the presence of alkalis tertiary amines do not react; under similar conditions secondary amines yield insoluble di-alkylphenyl sulphamides $C_6H_5SO_2NR_2$, whilst primary amines form mono-alkylphenyl sulphamides $C_6H_5SO_2NHR$, yielding soluble sodium salts $C_6H_5SO_2.NNaR$ with aqueous sodium hydroxide, but which are insoluble when produced by metallic sodium under ether. Dibenzene sulpho-alkyl amides $(C_6H_5SO_2)_2NR$ occur as subsidiary products which form similar sodium salts $C_6H_5SO_2N.NaR$ when warmed with sodium alcoholate (B. **38**, 908; C. 1906, II. 15).

(2*c*) The primary and secondary amines react similarly with 2,4-dinitro-bromobenzene or 2,4,6-trinitrochloro-benzene as with acid chlorides (B. **18**, R. 540), giving rise to di- and trinitrophenyl alkyl- and di-alkylamines.

(3) Primary and secondary amines combine with many inorganic and organic acid anhydrides—*e.g.* sulphur trioxide, acetic anhydride—to form amide-acids and acid amides.

(4) The behaviour of the amines towards nitrous acid is very characteristic. Primary amines are changed, at least in part, by this acid into their corresponding alcohols (p. 104):

$$C_2H_5NH_2+NO.OH=C_2H_5OH+N_2+H_2O.$$

This reaction corresponds with the decomposition of ammonium nitrite into water and nitrogen:

$$NH_3+NO.OH=H_2O+N_2+H_2O.$$

Primary amines containing secondary alkyl groups sometimes yield tertiary alcohols under these conditions, instead of the expected secondary alcohol. Nitrosyl chloride and bromide react with primary amines and give rise to alkyl chlorides and bromides (comp. p. 161).

Nitrous acid converts the secondary amines into *nitroso-amines* (p. 168):

$$(CH_3)_2NH+NO.OH=\underset{\text{Nitroso-dimethylamine.}}{(CH_3)_2N.NO}+H_2O$$

whereas the tertiary amines remain unaltered or undergo decomposition. Indeed, these reactions may be utilized in the separation of the amines, but naturally the primary amines are lost.

(5) Another procedure, resulting in a partial separation of the amines, depends on their varying behaviour towards carbon disulphide. The free bases (in aqueous, alcoholic, or ethereal solution) are digested with CS_2, when the primary and secondary amines form salts of alkyl dithiocarbaminic acid (*q.v.*), whilst the tertiary amines remain unaffected, and may be distilled off. On boiling the residue with $HgCl_2$ or $FeCl_3$, a part of the primary amine is expelled from the compound as mustard oil (*A. W. Hofmann*, B. **8**, 105, 461; **14**, 2754; and **15**, 1290).

(6) A marked characteristic of the primary amines is their ability to form *carbylamines* (*q.v.*), which are easily recognized by their odour (*A. W. Hofmann*, B. **3**, 767).

(7) By the action of Cl, Br, or I alone or in the presence of alkali hydroxide, primary and secondary amines yield alkylamine halides (p. 167).

(8) Alkyl magnesium halides (p. 185) react with primary and secondary amines, generating methane and forming RNHMgI and R_2NMgI; with tertiary amines a certain proportion of addition compounds is formed $R_3H{<}^{\text{Alk}}_{\text{MgI}}$.

(9) Oxidation produces varying results. Alkaline permanganate easily attacks all the amines; acid permanganate is less active, but still oxidizes with a velocity of reaction varying according to the structure of the amines, and produces ammonia, aldehyde, carboxylic acids and other bodies (B. **8**, 1237; A. **345**, 251).

In the presence of copper powder, oxygen acts on methylamine and ethylamine, producing formaldehyde and acetaldehyde respectively, together with ammonia (B. **39**, 178).

The various classes of amines can be characterized by their behaviour with hydrogen peroxide and persulphuric acid (B. **34**, 2499; **36**, 701, 710):

(*a*) Primary amines, RNH_2, and persulphuric acid yield various products according as R is a primary, secondary or tertiary alkyl radical. The first stage, however, in all cases is the formation of *alkyl hydroxylamines* RNHOH (p. 171), which are further oxidized to varying results. Alkylamines with primary alkyl groups yield, together with other bodies, hydroxamic acids (*q.v.*), easily detected by the *red colour* obtained with *ferric chloride;* alkylamines containing secondary groups give ketoximes (p. 153), and with tertiary alkyl groups yield nitroso-paraffins (p. 153).

(*b*) Secondary amines R_2NH yield *di-alkyl hydroxylamines* $R_2N.OH$ with hydrogen peroxide.

(*c*) Tertiary amines and hydrogen peroxide produce *tri-alkyl aminoxy-hydrates* $R_3N(OH)_2$ (p. 172).

10. Tertiary amines not only form addition compounds with oxygen (tri-alkyl aminoxy-hydrates) and alkyl halides (tetra-alkyl ammonium halides) as described, but also with *acid chlorides*. Such a compound, $R_3N{<}^{Cl}_{Acyl}$, is very labile, from which the acyl group is separated in the form of condensation products (B. **39**, 1631), or, when in presence of alcohols or amines, as acyl esters or acyl amines (B. **39**, 2135), together with the formation of tri-alkylamine hydrochlorides.

Cyanogen bromide also forms labile addition compounds with the trialkylamines, which immediately decompose into bromo-alkyls and dialkyl cyanamide, from which secondary amines can be produced. These reactions constitute a method of passing from the tertiary to the secondary amines (B. **38**, 1438). Similarly, hypochlorous acid and trimethylamine form dimethyl chloramine $(CH_3)_2NCl$ (comp. B. **38**, 2154).

Bromine and iodine also yield addition compounds with tertiary amines (B. **38**, 2715, 3904).

(*a*) Amines and Ammonium Bases with Saturated Alcohol Radicals

(1) **Primary Amines.**—**Methylamine**, $CH_3.NH_2$, b.p. —6°, occurs in *Mercurialis perennis* and *annua*, in bone-oil, and in the distillate from wood. It is produced from the methyl ester of isocyanic acid, by the reduction of chloropicrin, $CCl_3(NO_2)$, and hydrocyanic acid, and by the decomposition of various natural alkaloids, like *theïne*, *creatine*, and *morphine*. The best way of preparing it is by warming bromacetamide with potassium hydroxide (p. 159), or by the action of dimethyl sulphate (p. 158) on 10 per cent. ammonia at 0° (C. 1906, II. 1711).

Methylamine is a colourless gas, with an ammoniacal odour. Its combustibility in the air and the lack of solvent action of its aqueous solution on the oxides of cobalt, nickel, and cadmium distinguish it from ammonia. At 12° one volume of water dissolves 1150 volumes of the gas. Anhydrous lithium chloride absorbs considerable quantities of methylamine (C. 1898, II. 970), which also unites with silver chloride to form $CH_3NH_2.AgCl$ (C. 1897, I. 1156).

Methyl ammonium chloride, m.p. 210°. *Methyl ammonium picrate*, m.p. 207°, dissolves with difficulty.

Ethylamine, $C_2H_5.NH_2$, m.p. —84°, b.p. 18°; $D_8=0{\cdot}696$, is a mobile liquid, which mixes with water in all proportions (B. **33**, 638). It expels ammonia from ammoniacal salts, and when in excess redissolves aluminium hydroxide; otherwise it behaves in every respect like ammonia. Highly heated with potassium it becomes converted into potassium ethylamine C_2H_5NHK (C. 1897, I. 1157).

Propylamine $C_3H_7NH_2$, b.p. 49°. *Isopropylamine* $C_3H_7NH_2$, b.p. 32°, occurs in white-thorn. It is prepared by reduction of acetoxime $(CH_3)C{:}NOH$ (p. 158) (B. **20**, 505).

n.-*Butylamine* $C_4H_9NH_2$, b.p. 76°, and *Isobutylamine*, b.p. 68°, occur in fermentation butyl alcohol. Sec.-*Butylamine* $C_2H_5CH(CH_3)NH_2$, b.p. 63°, is obtained in its dextro-rotatory form $[\alpha]_D+7{\cdot}44°$ from the oil of *Cochlearea officinalis* (B. **36**, 582). Tert.-*Butylamine, Trimethyl Carbylamine*, b.p. 43°. n.-*Amylamine*

$C_5H_{11}NH_2$, b.p. 103°. *Isoamylamine* $(CH_3)_2CHCH_2CH_2NH_2$, b.p. 95°, is obtained when leucine is distilled with alkali hydroxides. It is miscible with water and burns with a luminous flame. Active *Amylamine* $C_2H_5CH(CH_3)CHNH_2$, b.p. 96°, $[\alpha]_D$ −5·86°, is produced from optically active amyl alcohol (p. 120) by means of amyl phthalimide (B. **37**, 1047). 1,1-*Dimethyl*-3-*aminobutane* $(CH_3)_3C.CH(NH_2).CH_3$, b.p. 103°, is obtained from pinacoline oxime (C. 1899, II. 474). *Diethyl Carbylamine* $(C_2H_5)_2CH.NH_2$, b.p. 90°. *Di-n.-propyl Carbylamine* $(C_3H_7)_2CH.NH_2$, b.p. 130°, *Diisobutyl Carbylamine* $(C_4H_7)_2CH.NH_2$, m.p. 166°, result from the corresponding ketoxime by reduction with sodium and alcohol (B. **27**, R. 200). n.-*Nonylamine* $C_9H_{19}.NH_2$, b.p. 195°, is already soluble with difficulty in water. n.-*Undecylamine* $CH_3[CH_2]_{10}NH_2$, m.p. 15°, b.p. 232°. 2-*Aminononane*, b.p.$_{11}$ 69°, and 2-*Aminoundecane*, b.p.$_{26}$ 114°, are obtained from heptyl and nonyl methyl ketoxime (B. **36**, 2554). n.-*Pentadecylamine* $CH_3[CH_2]_{12}NH_2$, m.p. 36°, b.p. 299° (C. 1899, II. 363) is produced from the corresponding acid chloramides (p. 160).

(2) **Secondary Amines.**—The secondary amines are also designated *imide bases.*

Simple Secondary Amines: Dimethylamine, $NH(CH_3)_2$, b.p. 72°, is most conveniently obtained by boiling nitrosodimethylaniline or dinitrodimethylaniline with potassium hydroxide (A. **222**, 119). It is a gas that dissolves readily in water. It is condensed to a liquid by the application of cold.

Diethylamine, $NH(C_2H_5)_2$, b.p. 56°, is a liquid, which is readily soluble in water; *hydrochloride,* m.p. 76°; *picrate,* m.p. 155°.

Di-n.-propylamine, b.p. 110°. *Diisopropylamine,* b.p. 84° (B. **22**, R. 343). *Mixed secondary amines* are produced by methods 3*a* and 3*b*. *Methyl Ethylamine,* b.p. 35°. *Methyl n.-Propylamine,* b.p. 63°. *Methyl n.-Butylamine,* b.p. 91°. *Methyl n.-Heptylamine,* b.p. 171° (B. **29**, 2110).

(3) **Tertiary Amines.**—These are also called *nitrile* bases, to distinguish them from *alkyl cyanides* or *acid nitriles.*

Trimethylamine, $N(CH_3)_3$, b.p. 35°, is isomeric with *ethyl methylamine,* $C_2H_5.NH.CH_3$, and the two propylamines, $C_3H_7.NH_2$. It is present in herring-brine, and is produced from *betaïne* (*q.v.*). It is prepared from herring-brine in large quantities, and also by the distillation of the "vinasses." It is conveniently obtained by heating ammonium chloride with formaldehyde (p. 158). Its penetrating, fish-like smell is characteristic. *Hydrochloride,* m.p. 271–275°; *picrate,* m.p. 216°, is sparingly soluble (B. **29**, R. 590).

Triethylamine, $N(C_2H_5)_3$, b.p. 89°, is not very soluble in water. It is produced by heating ethyl isocyanate with sodium ethoxide: $CO:N.C_2H_5+2C_2H_5.ONa=N(C_2H_5)_3+CO_3Na_2$.

(4) **Tetraalkyl Ammonium Bases.**—Whilst neither ammonium hydroxide nor mono-, di-, or tri-alkyl ammonium hydroxides have been prepared, yet, by the addition of the iodo-alkyls to the tertiary amines, tetra-alkyl ammonium iodides are produced; these, when treated with moist silver oxide, yield the alkyl *ammonium hydroxides:*

$$N(C_2H_5)_4I+AgOH=N(C_2H_5)_4.OH+AgI.$$

In the interaction of a methyl alcohol solution of tetramethyl ammonium chloride with a similar solution of potassium hydroxide, KCl is precipitated, and tetramethyl ammonium hydroxide $(CH_3)_4NOH$, is formed. It exists as a *pentahydrate,* m.p. 63°, a *trihydrate,* m.p. 60°, and a *monohydrate,* which breaks down into trimethylamine at 130–135° (C. 1905, II. 669).

These hydroxides are perfectly analogous to those of potassium and sodium. They possess a strong alkaline reaction, saponify fats, and deliquesce in the air. They crystallize when their aqueous solutions are concentrated in vacuo. With the acids they yield ammonium salts, which usually crystallize well.

On exposure to strong heat they break down into tertiary amines, and alcohols or their decomposition products (C_nH_{2n} and H_2O):

$$N(C_2H_5)_4.OH = N(C_2H_5)_3 + C_2H_4 + H_2O.$$

This reaction has acquired special significance because of its application in the decomposition of bases of ring-formation (see piperidine or pentamethylene imide).

Tetramethyl Ammonium Iodide, *Tetramethylium Iodide,* $N(CH_3)_4I$, and **Tetraethyl Ammonium Iodide,** *Tetraethylium Iodide,* $N(C_2H_5)_4I$, are prepared from trimethylamine and iodomethane, and iodoethane and triethylamine respectively; they consist of white prisms when crystallized from water or alcohol.

Other salts of the tetra-alkyl ammonium bases are only obtained with difficulty from the tri-alkylamines by addition, although sometimes the reaction of tertiary amines with dimethyl sulphate can be used with advantage for preparing methyl sulphuric acid salts $R_3C(CH_3)OSO_3CH_3$. The chlorides can be obtained by the action of silver chloride on the iodides.

Iodine Addition Products.—$(C_2H_5)_4NI.I_2$, $(C_2H_5)_4NI.2I_2$, and addition products containing even more iodine molecules, are precipitated by iodine from the aqueous solutions of the tetra-alkylium iodides, *e.g.* tetraethylium iodide.

Of the numerous compounds belonging here we may mention:

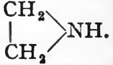
Dimethyl Diethyl Ammonium Iodide, $(CH_3)_2(C_2H_5)_2NI$, is obtained from dimethylamine and ethyl iodide, and from diethylamine and methyl iodide, methods of formation which should give rise to two substances having as constitutional formulæ:

$$(CH_3)(CH_3)(C_2H_5)N.C_2H_5I \text{ and } (C_2H_5)(C_2H_5)(CH_3)N.CH_3I.$$

These two compounds, however, are identical (A. **180**, 173). These facts, together with the existence and properties of tetra-alkyl ammonium hydroxide, show that the ammonium compounds are not molecular derivatives, as formerly assumed (the above formulæ are only intended to exhibit the different manner of formation), but represent true atomic compounds.

On the equivalence or the contrary of the five valencies of nitrogen in ammonium compounds, see *Le Bel,* B. **23**, R. 147. On the asymmetry and optical activity of tetra-alkyl ammonium compounds in which the substituting groups consist of four different monovalent alcoholic radicals, see B. **24**, R. 441; **32**, 3508; **33**, 1003.

(*b*) Unsaturated Amines and Ammonium Bases

Vinylamine, $CH_2{=}CH.NH_2$, has not yet been prepared. The previously ascribed compound is in reality ethylene imide  $\begin{array}{l} CH_2 \\ | \\ CH_2 \end{array}\!\!>NH$.

Trimethyl Vinyl Ammonium Hydroxide or Neurine, $CH_2{=}CH.N(CH_3)_3OH$, is described after glycol with choline (*q.v.*), to which it is intimately related.

Allylamine, $CH_2{=}CH.CH_2.NH_2$, b.p. 58°, is best obtained from mustard oil (*q.v.*). by boiling it with 20 per cent. hydrochloric acid (B. **30**, 1124).

Isoallylamine, Propenylamine, $CH_3.CH{=}CHNH_2$, b.p. 67°, is produced by the action of potassium hydroxide on β-bromopropylamine (B. **29**, 2747).

Undecenylamine, $C_{11}H_{21}NH_2$, b.p. 239°, and higher homologues, see B. **33**, 3580.

Dimethyl Piperidine, Pentallyl Dimethylamine, $CH_2{=}CH.CH_2.CH_2.CH_2.N(CH_3)_2$, b.p. 117–118°, is a decomposition product of piperidine (*q.v.*). This and similar bases unite with hydrochloric acid, and when heated yield ammonium chlorides of pyrrolidine bases (A. **278**, 1).

Propargylamine, $CH{\equiv}C.CH_2NH_2$, is prepared from dibromallylamine, $CH_2Br.CHBr.CH_2NH_2$, and potassium hydroxide. It is probably a gas in a free condition, but it can only be obtained in alcoholic solution or in the form of salts (B. **22**, 3080).

The following paragraphs, (*c*) to (*h*), deal with the alkylamine derivatives of inorganic acids, whilst the corresponding compounds of the carboxylic acids will be described with these later.

(*c*) Alkylamine Halides

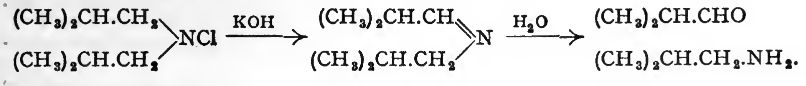
These bear the same relation to NCl_3 and NI_3 as the alkylamines to ammonia. The alkylamine chlorides and bromides may also be regarded as the amides of hypochlorous and hypobromous acids. Such derivatives are produced by the action of chlorine, bromine, or iodine, alone or in the presence of alkali hydroxides, on primary and secondary amines (B. **8**, 1470; **9**, 146; **16**, 558; **23**, R. 386; A. **230**, 222), as well as by the transposition of *acetodibromamide* (*q.v.*) with amines. When saponified they yield hypochlorous, hypobromous, and hypoiodous acids (B. **26**, 985):

$$CH_3CH_2CH_2NH_2 \longrightarrow CH_3CH_2CH_2NHCl \longrightarrow CH_3CH_2CH_2NCl_2$$
$$(CH_3CH_2CH_2)_2NH \longrightarrow (CH_3CH_2CH_2)_2NCl.$$

The primary alkylamine monohalides are less stable than the dihalides and the secondary halogen-amines.

Methyl Dichloramine, CH_3NCl_2, b.p. 58–60°, is prepared from methyl ammonium chloride and bleaching powder. It is a strongly smelling oil, exploding violently when heated. It forms diazomethane with hydroxylamine (p. 213; B. **28**, 1682). *Methyl Diiodamine*, CH_3NI_2, is garnet-red in colour. *Dimethyl Iodamine*, $(CH_3)_2NI$, is sulphur-yellow in colour. *Ethyl Dichloramine*, $C_2H_5NCl_2$, b.p. 88°, is a strongly smelling, unstable oil (B. **32**, 3582). *Propyl Chloramine*, C_3H_7NHCl, volatilizes with decomposition. *Propyl Dichloramine*, $C_3H_7NCl_2$, b.p. 117°, is a yellow oil. *Dipropyl Chloramine*, $(C_3H_7)_2NCl$, b.p. 143°, etc. (B. **8**, 1470; **9**, 146; **16**, 558; **23**, R. 386; **26**, R. 188; A. **230**, 222).

Secondary chloramines give up hydrochloric acid in the presence of alkalis and change to the alkyl imides of the aldehydes, which take up water in acid solutions forming a primary amide and an aldehyde:



$$\left.\begin{matrix}(CH_3)_2CH.CH_2\\(CH_3)_2CH.CH_2\end{matrix}\right\rangle NCl \xrightarrow{KOH} \left.\begin{matrix}(CH_3)_2CH.CH\\(CH_3)_2CH.CH_2\end{matrix}\right\rangle N \xrightarrow{H_2O} \begin{matrix}(CH_3)_2CH.CHO\\(CH_3)_2CH.CH_2.NH_2.\end{matrix}$$

This reaction can be employed for the identification of secondary amines (C. 1897, I. 745).

Nitriles result when the dibromides of the higher primary alkylamines are treated with alkalis.

(*d*) Sulphur Derivatives of the Alkylamines

1. **Thiodialkylamines,** *Thiotetralkyl Diamines*, result from the action of SCl_2 on dialkylamines in ligroïn solution. *Thiodiethylamine*, $S[N(C_2H_5)_2]_2$, b.p.$_{19}$ 87° (B. **28**, 575).

2. **Dithiotetralkylamines,** *Dithiotetralkyl Diamines*, result from the action of S_2Cl_2 on dialkylamines in ethereal solution. *Dithiodimethylamine*, $S_2[N(CH_3)_2]_2$, b.p.$_{22}$ 82°. *Dithiodiethylamine*, b.p.$_{22}$ 137° (B. **28**, 166).

3. **Alkyl-thionylamines,** alkylated imides of sulphurous acid, are formed when thionyl chloride (1 mol.) acts on a primary amine (3 mols.) in ethereal solution (*Michaelis*, A. **274**, 187):

$$3CH_3NH_2 + SOCl_2 = CH_3N{=}SO + 2CH\ NH_2.HCl.$$

The members of the series with low boiling points are liquids with penetrating odour, and fume in the air. Water decomposes them into SO_2 and the primary amine. *Thionyl Methylamine*, CH_3NSO, b.p. 58–59°. *Thionyl Ethylamine*, b.p. 70–75°. *Thionyl Isobutylamine*, $(CH_3)_2CH.CH_2.N:SO$, b.p. 117°.

4. **Thionyl Dialkylamines,** *Thionyl Tetralkyldiamines*, are formed when thionyl chloride acts on the ethereal solution of the dialkylamines. *Thionyl Diethylamine*, $OS[N(C_2H_5)_2]_2$, b.p.$_{27}$ 118°, corresponds in its composition with tetraethyl urea (B. **28**, 1016).

5. **Thionamic Acids** are the products resulting from the interaction of sulphur dioxide and primary amines: *ethyl thionamic acid*, $C_2H_5NH.SO_2H$, is a white hygroscopic powder.

6. **Alkyl Sulphamides** and **Alkyl Sulphaminic Acids.** *Sulphamides, e.g.* $SO_2{<}^{N(CH_3)_2}_{N(CH_3)_2}$, are formed by the action of sulphuryl chloride, SO_2Cl_2, on the free secondary amines, whereas their chlorides, $SO_2{<}^{NR_2}_{Cl}$ result when the HCl-salts are employed. Water converts the chlorides into sulphaminic acids. $SO_2{<}^{NR_2}_{OH}$ (A. **222**, 118). SO_3 reacts similarly with the primary and secondary amines, forming mono- and dialkylsulphaminic acids (B. **16**, 1265).

(*e*) Phosphorus Derivatives of the Secondary Alkylamines (B. 29, 710)

1. **Dialkylaminochlorophosphines** are prepared by the action of phosphorus trichloride on the dialkylamines. They are liquids which give off fumes in the air, and possess an irritating odour. *Diethylaminochlorophosphine*, $(C_2H_5)_2N.PCl_2$, b.p.$_{14}$ 73°. *Diisobutylaminochlorophosphine*, m.p. 37°, b.p.$_{16}$ 116°.

2. **Dialkylaminoxychlorophosphines** are obtained by the action of phosphorus oxychloride on secondary amines in aqueous solution. They are stable bodies, possessing a camphor- or pepper-like odour. *Diethylaminoxychlorophosphine*, $(C_2H_5)_2N.POCl_2$, b.p.$_{15}$ 100°. *Di-n-propylaminoxychlorophosphine*, b.p.$_{80}$ 170°. *Diisobutylaminoxychlorophosphine*, m.p. 54°.

3. **Dialkylaminosulphocholorophosphines** are formed when phosphorus sulphochloride acts on dialkylamines. They can be distilled in steam, and smell like camphor. *Diethylaminosulphochlorophosphine*, $(C_2H_5)_2N.PSCl_2$, b.p.$_{12}$ 100°. *Dipropylaminosulphochlorophosphine*, b.p.$_{15}$ 133°. *Diisobutylaminosulphochlorophosphine*, b.p.$_{10}$ 150°.

(*f*), (*g*), (*h*) Arsenic, Boron, and Silicon Derivatives of the Secondary Amines (B. 29, 714)

Diisobutylaminochlorarsine, $(C_4H_9)_2N.AsCl_2$, b.p.$_{15}$ 125°.

Diethylaminochloroborine, $(C_2H_5)_2N.BCl_2$, b.p. 142°. Fumes strongly in air. *Dipropylaminochloroborine*, b.p.$_{45}$ 99°. *Diisobutylaminochloroborine*, b.p.$_{17}$ 93°.

Diethylaminochlorosilicine, $(C_2H_5)_2N.SiCl_3$, b.p.$_{80}$ 104°. *Diisobutylaminochlorosilicine*, b.p.$_{30}$ 122°.

The chlorarsines, chloroborines, and chlorosilicines of the secondary bases are prepared in the same way as the chlorophosphines from the corresponding chlorides.

(*i*) Nitroso-amines

All basic secondary amines (imides), like $(CH_3)_2NH$ and $(C_2H_5)_2NH$, can be converted into nitroso-amines (nitrosamines) by the replacement of the hydrogen of the imide group. They are obtained from the free imides by the action of nitrous acid on their aqueous, ethereal, or glacial acetic acid solutions, or by warming their salts in aqueous or acid solution with potassium nitrite (p. 163) (B. **9**, 111). They are mostly oily, yellow liquids, insoluble in water, and may be distilled without decomposition. Alkalis and acids are usually without effect upon them; with phenol and sulphuric acid they give the nitroso-reaction. When reduced in alcoholic solution by means of zinc dust and acetic acid they become converted into hydrazines (p. 169). Boiling hydrochloric acid decomposes them into nitrous acid, and dialkylamines.

Dimethyl Nitrosamine, Nitrosodimethyline, $(CH_3)_2N.NO$, b.p. 148°.

Diethyl Nitrosamine, Nitrosodiethyline, b.p. 177°.

(*k*) Nitramines

are produced by the action of concentrated nitric acid on various amide derivatives of the primary amines, *e.g.* their urethanes or oxamides, from which the free mono-alkyl nitramines may be obtained by splitting off ammonia (B. **18**, R. 146; **22**, R. 295; C. 1898, I. 373):

$$CH_3NHCO_2CH_3 \longrightarrow CH_3N(NO_2)CO_2CH_3 \longrightarrow CH_3NH.NO_2 \text{ or } CH_3N{:}NOOH.$$

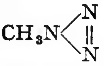
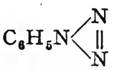
One hydrogen atom in the monoalkyl nitramine molecule is replaceable by an alkali metal, rendering the second formula RN : NOOH the more probably correct. As in the alkali salts of the nitroparaffins (p. 149) the metal is united to an oxygen atom forming a compound of the type RN : NOOMe. By the reaction of the potassium alkyl nitramines with the haloid alkyl compounds, there are produced the corresponding dialkyl nitramines, which yield unsym.-dialkyl hydrazines by reduction with zinc dust and acetic acid.

Methyl Nitramine $CH_3NH.NO_2$, m.p. 38°. *Ethyl Nitramine*, m.p. 3°. Potassium ethyl nitramine and iodomethane yield N-methyl ethyl nitramine (see below). *Propyl Nitramine*, b.p.$_{40}$ 128°. *O-Methyl Ethyl Isonitramine*, $C_2H_5.N : NO_2CH_3$, b.p.$_{20}$ 37° (C. 1898, I. 374), is prepared from silver ethyl nitramine. *Butyl Nitramine*, see B. **28**, R. 1058.

Simple N-Dialkyl Nitramines: *Dimethyl Nitramine*, $(CH_3)_2N.NO_2$, m.p. 58°, b.p. 187°, is produced, together with an isomer, b.p. 112°, by the distillation of monomethyl nitramine (B. **29**, R. 910), as well as upon treating dimethylamine and nitric acid with acetic anhydride (B. **28**, 402), from monomethyl nitramine and potassium nitrite (C. 1898, II. 477), and with diazomethane (B. **30**, 646). *Diethyl Nitramine*, b.p. 206°. *Dipropyl Nitramine*, b.p. 77°. **Mixed Nitramines:** *Methyl Ethyl Nitramine*, b.p. 190°. *Methyl Propyl Nitramine*, b.p. 115°. *Methyl Butyl Nitramine*, m.p. +0·5° (B. **29**, R. 424). *Methyl Allyl Nitramine*, b.p.$_{18}$, 95°, is obtained, together with an isomer, b.p.$_{18}$ 51°, by the interaction of potassium methyl nitramine and allyl bromide.

The alkyl hydrazines, alkyl diazo-compounds, alkylazides, and diazoamino paraffins (sections *l*, *m*, *n*, *o*), form classes of substances analogous to those which were first prepared and investigated in the aromatic series of organic compounds, where they exercised a great influence on the development of that section of chemistry (Vol. II.).

The analogy is seen in the following comparative lists:—

Methyl Hydrazine . .	$CH_3NH.NH_2$	$C_6H_5.NH.NH_2$	Phenyl Hydrazine.
Potassium Diazomethane	$CH_3N : NOK$	$C_6H_5.NCl : N$ $C_6H_5N : NOK$	Diazobenzene Chloride. Potassium Diazobenzene.
Methylazide	 $CH_3N\langle N \| N$	 $C_6H_5N\langle N \| N$	Phenyl Diazoimide.
Diazoaminomethane .	$CH_3N{:}N.NHCH_3$	$C_6H_5N{:}N.NC_6H_5$	Diazoaminobenzene.

(*l*) Alkyl Hydrazines

Just as the amines are derived from ammonia, so the hydrazines are derived from *hydrazine* or *diamide*, $H_2N.NH_2$, which can itself be obtained by the splitting up of diazoacetic acid (*q.v.*) or aminoguanidine (*q.v.*).

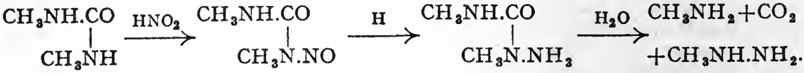
(1) If iodomethane acts on a cold aqueous solution of hydrazine, there are formed monomethyl hydrazine and unsym.-dimethyl hydrazine; with an excess

of iodomethane in the presence of alkalis, the final product is trimethyl hydrazonium iodide (B. **31**, 56):

$$NH_2.NH_2 \xrightarrow{CH_3I} NH_2.NHCH_3 \xrightarrow{CH_3I} NH_2.N(CH_3)_2 \xrightarrow{CH_3I} NH_2.N(CH_3)_3I.$$

Monoalkyl hydrazines also result by the heating of salts of alkyl sulphuric acid with an aqueous solution of hydrazine (B. **34**, 3268).

(2) Mono-alkyl and sym.-dialkyl urea, acted on by nitrous acid, give rise to nitroso-compounds which in turn yield hydrazine derivatives of urea (alkyl semicarbazides) on reduction. These are decomposed by boiling with alkalis or acids into alkylamine, CO_2 and *monoalkyl hydrazine:*



$$\begin{matrix} CH_3NH.CO \\ | \\ CH_3NH \end{matrix} \xrightarrow{HNO_2} \begin{matrix} CH_3NH.CO \\ | \\ CH_3N.NO \end{matrix} \xrightarrow{H} \begin{matrix} CH_3NH.CO \\ | \\ CH_3N.NH_2 \end{matrix} \xrightarrow{H_2O} \begin{matrix} CH_3NH_2+CO_2 \\ +CH_3NH.NH_2. \end{matrix}$$

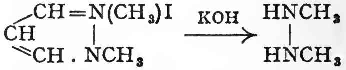
(3) unsym.-**Dialkyl Hydrazines**, on reduction with zinc dust and acetic acid, yield dialkyl nitrosamines (p. 168) or dialkyl nitramines (B. **29**, R. 424):

$$(CH_3)_2N.NO+4H=(CH_3)_2N.NH_2+H_2O.$$

Monoalkyl hydrazines are also obtained by reduction of the monoalkyl nitramines (p. 169).

(4*a*) sym.-**Dialkyl Hydrazines** are formed by the action of iodoalkyls on the lead or potassium salts of diformyl hydrazine, CHO.NH.NH.CHO, and the subsequent hydrolysis of the diformyl compound (B. **27**, 2279; **31**, 62; **39**, 3261).

(4*b*) Further, by heating pyrazole or pyrazolon (Vol. II.) with iodoalkyls and decomposing the resulting alkyl pyrazole iodoalkylate with aqueous potassium hydroxide (B. **39**, 3257, 3267):



The mono-alkyl hydrazines reduce Fehling's solution in the cold, and the dialkyl hydrazines when warmed. This behaviour differentiates them from the amines, which they otherwise resemble closely.

Methyl Hydrazine, $CH_3.NH.NH_2$, b.p. 87°, is a very mobile liquid. Its odour is like that of methylamine. It absorbs moisture and fumes in the air (B. **22**, R. 670).

Ethyl Hydrazine, $(C_2H_5)HN.NH_2$, b.p. 100°.

When ethyl hydrazine is acted on by potassium pyrosulphate, *potassium ethyl hydrazine sulphonate*, $C_2H_5.NH—NH.SO_3K$, is formed. Mercuric oxide changes this to *potassium diazoethyl sulphonate*, $C_2H_5.N=N.SO_3K$.

sym.-*Dimethyl Hydrazine*, $CH_3NH.NHCH_3$, b.p. 81°, forms salts with mono- and di-basic acids. sym.-*Diethyl Hydrazine*, b.p. 85°.

unsym.-*Dimethyl Hydrazine*, $(CH_3)_2N.NH_2$, b.p. 62°, and unsym.-*Diethyl Hydrazine*, b.p. 97°, are mobile liquids, possessing an ammoniacal odour; they are soluble in water, alcohol and ether. *Thionyl Diethyl Hydrazine*, $(C_2H_5)_2N.N:SO$, b.p.$_{20}$ 73° (B. **26**, 310).

Trimethyl Hydrazonium Iodide, $NH_2.N(CH_3)_3I$, m.p. 235°, with decomposition, resembles tetramethyl ammonium iodide. Moist silver oxide liberates the strongly alkaline *tetramethyl hydrazonium hydroxide*, $NH_2N(CH_3)_3OH$; this consists of hydroscopic crystals, which are partially decomposed on distillation into unsym.-dimethyl hydrazine and methyl alcohol. Heating with iodomethane breaks down the molecule into tetramethyl ammonium iodide, nitrogen, and hydrogen. *Tetraethyl Hydrazonium Iodide* is prepared from diethyl hydrazine and iodoethane (A. **199**, 318; B. **31**, 57).

(*m*) Alkyl Diazo-Compounds

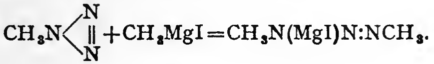
Potassium Diazoethane Sulphonate, $C_2H_5N=N.SO_3K$ (*q.v.*), obtained from potassium ethyl hydrazine sulphonate, and the potassium salt of *diazomethane* or *methyl azoic acid* ($CH_3N{=}N.OK$), prepared from diazomethane (p. 213) are two representatives of this class of compounds.

(*n*) Alkyl Diazoimides

Methyl Diazoimide, Methylazide, $CH_3.N_3$, b.p. 20°, $D^8_{15}=0{\cdot}869$, is the methyl ester of hydrazoic acid, and is obtained from the sodium hydrozoate NaN_3 and dimethyl sulphate in alkaline solution. It explodes violently above 500° (B. **38**, 1573).

(*o*) Diazoamino Paraffins

Diazoamino-methane, Dimethyl Triazene, $CH_3N:N.NHCH_3$, m.p. −12°, b.p. 93°, is a colourless liquid, having an odour resembling alkaloids. It is poisonous, it dissolves in water, and explodes violently on sudden heating. Its magnesium salt is produced from methyl azide and methyl magnesium iodide:



$$CH_3N\left\langle\begin{matrix}N\\ \|\\ N\end{matrix}\right. + CH_3MgI = CH_3N(MgI)N:NCH_3.$$

This substance is decomposed by water.

The *silver* compound $CH_3N_2.NAgCH_3$ exists as colourless needles, and the *copper* compound $CH_3N_2.NCu(CH_3)$ as yellow crystals (B. **39**, 3905). Diazoamino methane is very easily decomposed by acids, evolving nitrogen and splitting into methylamine and a methyl ester:

$$CH_3N:NHCH_3+2HCl=CH_3Cl+N_2CH_3NH_2.HCl.$$

(*p*) Tetra-alkyl Tetrazones

When mercuric oxide acts on unsym.-diethyl hydrazine, $(C_2H_5)_2N.NH_2$, *tetraethyl tetrazone*, $(C_2H_5)_2N.N:N.N(C_2H_5)_2$, is formed. This is a strongly basic liquid with an alliaceous odour.

Methyl Butyl Tetrazone, b.p.$_{19}$ 121° (B. **29**, R. 424).

(*q*) Alkyl Hydroxylamines

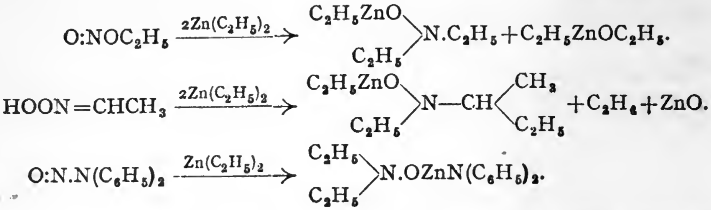
The entry of one alkyl group into hydroxylamine produces two isomeric forms:

$NH_2.O.CH_3$	and	$CH_3.NH.OH$.
α-Methyl-hydroxylamine.		β-Methyl-hydroxylamine.

The derivatives of both varieties are obtained from the isomeric benzaldoximes (*q.v.*). The β-compounds are formed from syn-meta-nitrobenzaldoxime by alkylization with sodium alcoholate and an iodoalkyl, together with the subsequent separation of the ether by means of concentrated hydrochloric acid (B. **23**, 599; **26**, 2377, 2514). α-Derivatives result from the breaking down of alkyl benzhydroxamic esters. The β-compounds are intermediate products in the reduction of the nitro-paraffins with stannous chloride, or, better, with zinc dust and water (B. **27**, 1350), and can also be prepared by electrolytic reduction (C. 1899, II. 200). β-Alkyl hydroxylamines also occur as intermediate products during the oxidation of primary amines with permonosulphuric acid, H_2SO_5, but they are mainly oxidized further to aldoximes, hydroxamic acids, ketoximes, nitroso- and nitro-compounds (p. 164).

Alkylation of hydroxylamine results essentially in the formation of β-dialkyl hydroxylamines, which in turn lead to the formation of the hydriodic acid salts of the trialkylamine oxides (p. 172).

β-Dialkyl hydroxylamines are also formed during the oxidation of the dialkylamines (B. **34**, 2499). They further result by treatment with water of the reaction products of zinc alkyls or zinc or magnesium alkyl halides on alkyl nitrites, nitro-paraffins (J. pr. Ch. [2] **63**, 94, 193; B. **40**, 3065) and diphenyl nitrosamine (B. **33**, 1022). During the course of the last three reactions the following intermediate products are probably formed, if we take as examples ethyl nitrite, nitroethane (in the acid form) and diphenyl nitrosamine with zinc ethyl:



$$O{:}NOC_2H_5 \xrightarrow{2Zn(C_2H_5)_2} \left.\begin{matrix}C_2H_5ZnO\\C_2H_5\end{matrix}\right>N.C_2H_5+C_2H_5ZnOC_2H_5.$$

$$HOON{=}CHCH_3 \xrightarrow{2Zn(C_2H_5)_2} \left.\begin{matrix}C_2H_5ZnO\\C_2H_5\end{matrix}\right>N{-}CH\left<\begin{matrix}CH_3\\C_2H_5\end{matrix}\right.+C_2H_4+ZnO.$$

$$O{:}N.N(C_6H_5)_2 \xrightarrow{Zn(C_2H_5)_2} \left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right>N.OZnN(C_6H_5)_2.$$

β-Dialkyl hydroxylamines are conveniently prepared by the action of nitric oxide on magnesium alkyl iodides in solution in ether (B. **36**, 2315).

$$2NO_2+4C_2H_5MgI \longrightarrow 2(C_2H_5)_2NOMgI+MgO+MgI_2.$$

Reduction changes the β-dialkyl hydroxylamines into dialkylamines: when sulphurous acid is employed they are converted into dialkyl sulphaminic acids (B. **33**, 159). See further under Trialkylamine oxides.

a-Methyl Hydroxylamine, Methoxylamine, $NH_2.O.CH_3$, yields a *hydrochloride,* m.p. 149°. It differs from hydroxylamine in that it does not reduce alkaline copper solutions.

a-Ethyl Hydroxylamine, Ethoxylamine, $NH_2.O.C_2H_5$, b.p. 68°.

β-Methyl Hydroxylamine, $CH_3.NH.OH$, m.p. 41°, b.p.$_{16}$ 61° (B. **23**, 3597; **24**, 3528; **25**, 1716; **26**, 2514).

β-Ethyl Hydroxylamine, m.p. 59°.

β-Diethyl Hydroxylamine $(C_2H_5)_2N.OH$, b.p.$_{36}$ 76°.

β-Dipropyl Hydroxylamine, $(C_3H_7)_2N.OH$, m.p. 29°, b.p. 150°.

Ethyl-sec. Butyl Hydroxylamine, $C_2H_5N(OH)CH.(CH_3).C_2H_5$, b.p. 155°, prepared from nitroethane and zinc ethyl, was previously thought to be triethylamine oxide (C. 1901, I. 1146; II. 185).

a β-Diethyl Hydroxylamine, $C_2H_5NHOC_2H_5$, b.p. 83°, and *Triethyl Hydroxylamine,* $(C_2H_5)_2NOC_2H_5$, b.p. 98°, are formed by the action of C_2H_5Br on ethoxylamine (B. **22**, R. 590).

(*r*) Trialkylamine Oxides

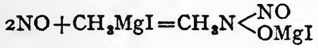
These are obtained as salts of hydriodic acid, $R_3N\left<\begin{matrix}OH\\I\end{matrix}\right.$ by the action of iodoalkyls on hydroxylamine and the intermediate β-dialkyl hydroxylamines; also by oxidation of the trialkylamines by H_2O_2 (B. **34**, 2499). The free oxide is unknown, but the corresponding hydrate, a deliquescent body, has been obtained, as in the case of the hydrate of *Triethylamine Oxide Hydrate,* $(C_2H_5)_3N(OH)_2$. The trialkylamine residue plays a similar part to that of a metal of the alkali earths in the corresponding hydroxides. The trimethyl compound is decomposed by heat into dimethylamine and formaldehyde, whilst the *Tripropylamine Oxide Hydrate* is broken up into β-dipropyl hydroxylamine and propylene. Sulphurous acid converts it into tripropylamine when heated; in the cold it forms an addition product $(C_3H_7)_3N\left<\begin{matrix}SO_2\\|\\O\end{matrix}\right.$, m.p. 159°, which is deposited as tiny crystals possessing a silky sheen (B. **34**, 2501).

(*s*) Nitroso-β-alkyl Hydroxylamines

A member of this class of bodies was probably discovered by ***Frankland,*** and described under the name of *Dinitro ethylic acid.* It is prepared by the action of NO on zinc ethyl and the subsequent decomposition by water of the addition compound formed, and is designated as *nitroso-β-ethyl hydroxylamine* (B. **33**, 1024):

$$CH_3CH_2N\left<\begin{matrix}NO\\OZnC_2H_5\end{matrix}\right. \longrightarrow CH_3CH_2N\left<\begin{matrix}NO\\OH\end{matrix}\right.$$

Similarly a salt of *nitroso-β-methyl hydroxylamine* is prepared from NO—which reacts according to the constitutional formula O : H—N:O—and magnesium methyl iodide in solution in ether :



$$2NO + CH_3MgI = CH_3N{<}\begin{matrix}NO\\OMgI\end{matrix}$$

which gives the Liebermann nitroso-reaction, and yields a well crystallized *copper* salt, $(CH_3N_2O_2)_2Cu + \frac{1}{2}H_2O$.

6. PHOSPHORUS DERIVATIVES OF THE ALCOHOL RADICALS

A. PHOSPHORUS BASES OR PHOSPHINES AND ALKYL PHOSPHONIUM COMPOUNDS

Hydrogen phosphide, PH_3, has slight basic properties. It unites with HI to form phosphonium iodide, which is resolved again by water into its components. The *phosphorus bases or phosphines*, obtained by the replacement of the hydrogen of PH_3 by alkyls, have more of the basic character of ammonia and approach the amines in this respect. The basic character increases with the number of alkyl groups.

(1) They are oxidized very energetically on exposure to the atmosphere, usually with spontaneous ignition ; hence they must be prepared in the absence of air. Moderate oxidation with nitric acid converts the primary phosphines into *alkyl phosphoric acids*, the secondary phosphines into *alkyl phospho-acids*, whilst the tertiary phosphines, in the presence of air, pass into *alkyl phosphinic oxides :*

Ethyl Phosphine : $C_2H_5PH_2 \longrightarrow C_2H_5PO(OH)_2$—Ethyl Phosphoric Acid.
Diethyl Phosphine : $(C_2H_5)_2PH \longrightarrow (C_2H_5)_2PO(OH)$—Diethyl Phosphinic Acid.
Triethyl Phosphine : $(C_2H_5)_3P \longrightarrow (C_2H_5)_3PO$—Triethyl Phosphine Oxide.

(2) They combine readily with sulphur and carbon disulphide (B. **25**, 2436) ; also with the halogens.

(3) The primary phosphines, are, like PH_3, feeble bases. Their salts, such as PH_4I, are decomposed by water. Potassium hydroxide is required for the decomposition of the salts of the secondary and tertiary phosphines.

(4) The tertiary phosphines combine with the alkyl iodides to form tetra-alkyl phosphonium iodides. These are just as little decomposed by potassium hydroxide as the tetra-alkyl ammonium iodides. Moist silver oxide liberates *tetra-alkyl phosphonium hydroxides* from them ; these, like the tetra-alkyl ammonium hydroxides, are stronger bases than the alkalis :

$$P(CH_3)_3 \xrightarrow{CH_3I} P(CH_3)_4I \xrightarrow{AgOH} P(CH_3)_4OH.$$

Thénard (1846) discovered the tertiary phosphines, and *A. W. Hofmann* (1871) first prepared the primary and secondary phosphines (B. **4**, 430).

Formation.—(1) By the reaction between alkyl iodides and phosphonium iodide for six hours in the presence of certain metallic oxides, chiefly zinc oxide, at 150°. The product, in the case of ethyl iodide, is a mixture of $P(C_2H_5)H_2.HI$ and $P(C_2H_5)_2H.HI$, the first of which is decomposed by water. The HI-salt of the diethyl phosphine is not affected, but by boiling the latter with sodium hydroxide, diethyl phosphine is set free (*A. W. Hofmann*) :

$$2PH_4I + 2C_2H_5I + ZnO = 2[P(C_2H_5)H_2.HI] + ZnI_2 + H_2O.$$
$$PH_4I + 2C_2H_5I + ZnO = P(C_2H_5)_2H.HI \quad + ZnI_2 + H_2O.$$
$$P(C_2H_5)H_2HI \xrightarrow{H_2O} P(C_2H_5)H_2 + HI.$$

(2) Tertiary phosphines and phosphonium iodides are produced by heating phosphonium iodide with alkyl iodides (methyl iodide) to 150–180° without the addition of metallic oxides. They can be separated by means of potassium hydroxide:

$$PH_4I+3CH_3I=P(CH_3)_3.HI+3HI.$$
$$P(CH_3)_3HI+CH_3I=P(CH_3)_4.I+HI.$$

(3) Tertiary phosphines result when alkylogens act on calcium phosphide (*Thénard*), and (4) in the action of zinc alkyls on phosphorus chloride:

$$2PCl_3+3Zn(CH_3)_2=2P(CH_3)_3+3ZnCl_2.$$

(Compare the action of mercury alkyls on PCl_3, p. 175.)

(4) Primary phosphines are also obtained by heating monoalkyl phosphinous acids (p. 175).

The *phosphines* are colourless, strongly refracting, extremely powerful-smelling, volatile liquids. They are scarcely soluble in water, but dissolve readily in alcohol and ether. They oxidize very readily and have a neutral reaction.

(1) **Primary Phosphines:**

Methyl Phosphine, $P(CH_3)H_2$, condenses at −14° to a mobile liquid.

Ethyl Phosphine, $P(C_2H_5)H_2$, b.p. 25°.

n-Propyl Phosphine, $P(C_3H_7)H_2$, b.p. 53° (C. 1903, II, 987).

Isopropyl Phosphine, $P(C_3H_7)H_2$, b.p. 41°, *Isobutyl Phosphine*, $P(C_4H_7)H_2$, b.p. 62°. Fuming nitric acid oxidizes the primary phosphines to *alkyl phospho-acids;* their HI-salts are decomposed by water.

(2) **Secondary Phosphines:**

Dimethyl Phosphine, $P(CH_3)_2H$, b.p. 25° C.

Diethyl Phosphine, $P(C_2H_5)_2H$, b.p. 85°.

Diisopropyl Phosphine, $P(C_3H_7)_2H$, b.p. 118°. *Diisoamyl Phosphine*, $P(C_5H_{11})_2H$, b.p. 210–215°, is not spontaneously inflammable. Fuming nitric acid oxidizes this class of phosphines to *dialkyl phosphinic acids.*

Water does not decompose the HI-salts of the secondary phosphines.

(3) **Tertiary Phosphines:**

Trimethyl Phosphine, $P(CH_3)_3$, b.p. 40°. *Triethyl Phosphine*, $P(C_2H_5)_3$, b.p. 127°. Both tertiary phosphines form phosphine oxides by the absorption of oxygen (B. **29**, 1707). They also combine with S, Cl_2, Br_2, the halogen acids, and the alkylogens. Carbon disulphide also combines with triethyl phosphine, and the product is $P(C_2H_5)_3.CS_2$, b.p. 95°, crystallizing in red leaflets. It is insoluble in water, and sublimes without decomposition. Its production serves for the detection of carbon disulphide.

According to almost all of these reactions, triethyl phosphine resembles a strongly positive bivalent metal—for example, calcium. By the addition of three alkyl groups, the quinquivalent, metalloidal phosphorus atom acquires the character of a bivalent alkali-earth metal. By the further addition of an alkyl group to the phosphorus in the phosphonium group, $P(CH_3)_4$, the former acquires the properties of a univalent alkali metal. Similar conditions are to be observed with sulphur, tellurium, arsenic, and also with almost all the less positive metals.

(4) *Phosphonium Bases.*—The *tetra-alkyl phosphonium bases* resemble, in a very high degree, both in formation and properties, the tetra-alkyl ammonium bases. *Tetramethyl-* and *Tetraethyl phosphonium hydroxide*, $P(C_2H_5)_4.OH$, are crystalline masses which deliquesce on exposure to the air. They possess a strongly alkaline reaction. When they are heated they show the great affinity of phosphorus for oxygen, for, unlike the corresponding ammonium derivatives, they break down into a *trialkyl phosphine oxide* and a paraffin. Thus *tetramethyl phosphonium hydroxide* yields trimethyl phosphine oxide and methane:

$$P(CH_3)_4.OH=P(CH_3)_3O+CH_4.$$

Tetramethyl- and *Tetraethyl Phosphonium Iodide*, $P(C_2H_5)_4I$, are white, crystalline substances, which are decomposed by heat into trialkyl phosphines and alkyl iodides. Tetraethyl phosphonium periodide results from the prolonged interaction of iodoethane and phosphorus at 180°. With H_2S it changes into the normal iodide (B. **22**, R. 348).

B. ALKYL PHOSPHO-ACIDS

These acids result, as mentioned previously, from the moderated oxidation of the primary phosphines with nitric acid; and also by oxidation of mono-alkyl phospho-acids (see below). They are derived from *unsymmetrical phosphorous acid*, $HPO(OH)_2$.

Methyl Phospho-acid, $CH_3PO(OH)_2$, m.p. 105°. PCl_5 converts it into the *chloride*, CH_3POCl_2, m.p. 32°, b.p. 163°. On the formation of similar chlorides from alkyl-tetrachlorophosphines, see below. *Ethyl Phospho acid*, $C_2H_5PO(OH)_2$, m.p. 44°.

The dialkyl esters of alkyl phospho acid, *e.g. Diethyl Ester* of *Propyl Phospho-acid*, $C_3H_7PO(OC_2H_5)_2$, b.p.$_{8.5}$ 87°, are obtained from the addition products of sym.-phosphorous acid ester (p. 141) and alkyl iodides (C. 1906, II. 1640; B. **31**, 1048), and from the interaction of alkyl oxychlorophosphines (see below) and sodium alcoholates.

C. ALKYL PHOSPHINIC ACIDS

These are derived from *hypophosphorous acid*, $H_2PO(OH)$.

(1) **Mono-alkyl Phosphinic Acids.**

The action of mercury alkyls on PCl_3 results in the formation of *alkyl chlorophosphines*:

$$(C_2H_5)_2Hg+PCl_3=C_2H_5HgCl+C_2H_5PCl_2.$$

Ethyl Chlorophosphine, b.p. 114–117°, $D_{19}=1{\cdot}295$. *Propyl Chlorophosphine*, b.p. 140–143°, $D_{19}=1{\cdot}177$. *Isoamyl Chlorophosphine*, b.p. 180–183°, $D_{23}=1{\cdot}102$. Water decomposes these chlorides into the corresponding *alkyl phosphinic acids*. RPO_2H_2. They are syrupy liquids which are decomposed into alkyl phosphines and alkyl phospho acids when heated:

$$3C_5H_{11}PO_2H_2=C_5H_{11}PH_2+2C_5H_{11}PO_3H_2$$

Chlorine combines with the alkyl chlorophosphines forming alkyl tetrachlorophosphines, $RPCl_4$, which resemble phosphorus pentachloride. Heat causes partial dissociation into PCl_3 and chloro-alkyl; SO_2 produces thionyl chloride and **alkyl oxychlorophosphines**, $RPOCl_2$; *ethyl oxychlorophosphine*, b.p.$_{50}$ 75–80°; *propyl oxychlorophosphine*, b.p.$_{50}$ 88–90°.

The alkyl chlorophosphines heated with sulphur form *alkyl sulphochlorophosphines*, $RPSCl_2$; *ethyl sulphochlorophosphine*, b.p.$_{50}$ 81° (B. **32**, 1572).

(2) **Dialkyl Phosphinic Acids** result from oxidation of *secondary phosphines* by fuming nitric acid. *Dimethyl Phosphinic Acid*, $(CH_3)_2PO(OH)$, m.p. 76°, forms a paraffin-like mass, which volatilizes undecomposed. *Diethyl Dithiophosphinic Acid*, $(C_2H_5)_2PS.SH$, see B. **25**, 2441.

D. ALKYL PHOSPHINE OXIDES

arise (1) when the tri-alkyl phosphines are oxidized in the air, together with alkyl esters of dialkyl phosphinic acid, R_2PO_2R, and alkyl phospho acids, RPO_3R_2 (B. **31**, 3055), or by mercuric oxide; (2) in the decomposition of the *tetra-alkyl phosphonium hydroxides* by heat; (3) from $POCl_3$ and magnesium alkyl haloids:

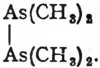
$$POCl_3+3RMgX=OPR_3+3MgXCl.$$

The trialkyl phosphine oxides combine with acids similarly to the trialkylamine oxides (p. 172) (C. 1906, I. 1484). *Triethyl Phosphine Oxide*, $P(C_2H_5)_3O$, m.p. 53°, b.p. 243°, forms, for example, $P(C_2H_5)_3Cl_2$, with haloid acids, from which sodium regenerates *triethyl phosphine* by the aid of heat. The corresponding *triethyl phosphine sulphide*, $P(C_2H_5)_3S$, m.p. 94°, is prepared from triethyl phosphine and sulphur.

7, ALKYL DERIVATIVES OF ARSENIC

Arsenic is somewhat metallic in character; its alkyl compounds constitute the transition from the nitrogen and phosphorus bases to the so-called metallo-organic derivatives—*i.e.* the compounds of the alkyls with the true metals (p. 183). The similarity to the amines and phosphines is observed in the existence of tertiary arsines, $As(CH_3)_3$, but these do not possess basic properties, nor do they unite with acids. They show in a marked degree the property of the tertiary phosphines, in their uniting with oxygen, sulphur, and the halogens to form compounds of the type $As(CH_3)_3X_2$, and with halogen alkyls to form quaternary arsonium compounds $As(CH_3)_4X$. The mono-, di-, and tri-alkyl arsines, derived from AsH_3, have not played nearly as important a *rôle* in the development of organic chemistry as have the cacodyl compounds.

In 1760 *Cadet* discovered the reaction which led to the study of the arsenic alkyls. He distilled arsenious acid together with potassium acetate, and obtained a liquid which was subsequently named, after its discoverer, *Cadet's fuming arsenical liquid.* From 1837 to 1843 *Bunsen* carried out a series of splendid investigations (A. **37**, 1; **42**, 14; **46**, 1), and demonstrated that the chief constituent of *Cadet's* liquid was "alkarsine," or cacodyl oxide, whose radical "cacodyl" *Bunsen* also succeeded in preparing. *Berzelius* proposed the name *cacodyl* (from κακώδης, *stinking*) for this very poisonous body with an extremely repulsive odour. *Bunsen* showed that it behaved like a compound radical. Together with the *cyanogen* of *Gay-Lussac*, and the *benzoyl* of *Liebig* and *Wöhler*, which was assumed to be present in the *benzoyl* derivatives, it formed a strong support for the radical theory. But later it was found that cacodyl was no more a free radical than was cyanogen, but that, in accordance with the doctrine of valence, it was rather a compound of two univalent radicals—$As(CH_3)_2$, combined to a saturated molecule:



$$\begin{array}{l} As(CH_3)_2 \\ | \\ As(CH_3)_2. \end{array}$$

Valuable contributions have been made to the chemistry of the arsenic alkyls by *Cahours* and *Riche* (A. **92**, 361), by *Landolt* (A. **92**, 370), and particularly by *Baeyer*, who discovered the monomethyl arsenic derivatives, and made clear the connection existing between the alkyl-arsenic derivatives (A. **107**, 257).

The following reactions give rise to arsenic alkyl compounds :—

(1) *Cacodyl Oxide*, or *Alkarsine*, is produced by the distillation of potassium acetate and arsenious acid. This is a delicate test, both for arsenic and for acetic acid :

$$4CH_3.CO_2K + As_2O_3 = [(CH_3)_2As]_2O + 2K_2CO_3 + 2CO_2.$$

(2) Also, by the action of zinc alkyls on arsenic trichloride ; and (3) by the action of the alkyl iodides on sodium arsenide produces *trialkarsine* together with tetra-alkyl diarsine (*ethyl cacodyl*).

$$2AsCl_3 + 3Zn(CH_3)_2 = 2As(CH_3)_3 + 3ZnCl_2.$$
$$AsNa_3 + 3C_2H_5I = As(C_2H_5)_3 + 3NaI.$$

(4) The interaction of trisodium or tripotassium arsenite and alkyl iodides gives rise to the sodium salts of alkyl arsonic acid (A. **249**, 147 ; C. 1905, I. 860), which reaction is similar to that of the formation of alkyl sulphonic acid salts from potassium sulphite and iodoalkyls (p. 146).

$$K_3AsO_3 + CH_3I = CH_3AsO(OK)_2 + KI.$$

The method for alkylating arsenic can be pushed further for the production of di- and tri-alkyl compounds. Methyl arsenic oxide, obtained from methyl arsenic acid by reduction with SO_2 (see below), yields cacodylic acid or dimethyl arsenious acid by the action of iodomethane and alkalis :

$$CH_3AsO + 2KOH + CH_3I = (CH_3)_2AsOOK + KI + H_2O.$$

Cacodyl oxide, obtained by reduction of cacodylic acid, or from arsenic direct gives trimethyl arsenic oxide, when treated with iodomethane and alkali (C. 1904, I. 80):

$$(CH_3)_2AsOH + KOH + CH_3I = (CH_3)_3AsO + KI + H_2O.$$

MONOALKYL-ARSINE COMPOUNDS

The formation of monomethyl arsenic chloride, $As(CH_3)Cl_2$, results from the property possessed by the derivatives of the type AsX_3, of adding two halogen atoms (Cl_2) and passing into compounds of the form AsX_5. The more chlorine atoms these bodies contain, the more readily do they split off methyl chloride. Thus $As(CH_3)Cl_4$ breaks down, at 0°, into $AsCl_3$ and CH_3Cl; and $As(CH_3)_2Cl_3$, at 50°, into $As(CH_3)Cl_2$ and CH_3Cl:

$$\begin{array}{llll} As(CH_3)_3 & \xrightarrow{+Cl_2} As(CH_3)_3Cl_2 & \xrightarrow{\quad} & CH_3Cl + As(CH_3)_2Cl \\ As(CH_3)_2Cl & \xrightarrow{+Cl_2} As(CH_3)_2Cl_3 & \xrightarrow{50^\circ} & CH_3Cl + As(CH_3)Cl_2 \\ As(CH_3)Cl_2 & \xrightarrow{+Cl_2} As(CH_3)Cl_4 & \xrightarrow{0^\circ} & CH_3Cl + AsCl_3. \end{array}$$

These reactions are the reverse of those described (method no. 4) for the progressive elaboration of methyl-arsenic compounds from arsenic.

Methyl Arsine Dichloride, CH_3AsCl_2, b.p. 133°, results from cacodyl trichloride, $(CH_3)_2AsCl_3$ (see above), or cacodylic acid by the action of HCl, also from methyl arsenic acid (see below) and an excess of PCl_3 (C. 1906, II. 101). It is a heavy, water-soluble liquid. Similarly, *Methyl Arsine Diiodide*, CH_3AsI_2, is obtained from methyl arsenic acid by reduction by SO_2, followed by precipitation with HI. The methyl arsine dihalide yields *Methyl Arsenoxide*, CH_3AsO, m.p. 95°, by the action of Na_2CO_3; with H_2S is formed *Methyl Arsine Sulphide*, CH_3AsS, m.p. 110°; and with Ag_2O the silver salt of methyl arsenic acid is obtained.

Methyl Arsenic Acid, $CH_3AsO(OH)_2$, m.p. 161°, and *Ethyl Arsenic Acid*, $C_2H_5AsO(OH)_2$, are best prepared from potassium arsenite and iodoalkyls in aqueous solution (see above); boiling magnesia mixture precipitates the magnesium salt (C. 1905, I. 800). The sodium salt of methyl arsenic acid is employed medicinally under the name of *Arrhenal* (comp. C. 1905, I. 1699). Reduction of methyl and ethyl arsenic acids with hypophosphite in a sulphuric acid solution leads to the formation of *Methyl* and *Ethyl Arsenic* $(CH_3As)_x$ and $(C_2H_5As)_x$ as yellow easily polymerisable oils (C. 1904, II. 415; 1906, I. 730).

Methyl Arsine, CH_3AsH_2, b.p. +2°, and *Ethyl Arsine*, $C_2H_5AsH_2$, b.p. 36°, result from reduction of the alkyl arsenic acids by amalgamated zinc dust, alcohol, and hydrochloric acid. They are colourless liquids of a cacodyl-like odour, very poisonous, and form salts with acids with great difficulty or not at all. Methyl arsine is not spontaneously inflammable. Oxidation leads first to methyl arsenoxide and then to methyl arsenic acid; iodoalkyls give rise to the alkylarsines, *e.g.* tetraalkyl arsonium iodide (B. **34**, 3594; C. 1905, I. 799).

DIALKYL ARSINE DERIVATIVES

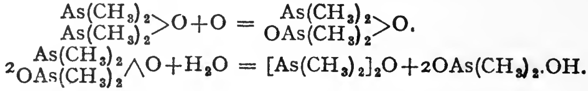
Cacodylic Oxide, *Alkarsine,* $\begin{matrix}(CH_3)_2As\\(CH_3)_2As\end{matrix}\!>\!O$, m.p. −25°, b.p. 120°, $D_{15} = 1{\cdot}462$, is the parent substance for the preparation of the dimethyl compounds. Its formation from potassium acetate and arsenic trioxide has already been given on p. 176. The crude oxide ignites spontaneously in the air. This is due to the presence in it of a slight amount of free cacodyl. When prepared from *cacodyl chloride* by potassium hydroxide it does not inflame spontaneously, and consists of a liquid with a stupefying odour. It is insoluble in water, but readily soluble in alcohol and in ether.

Dimethyl Arsine, *Cacodyl Hydride,* $(CH_3)_2AsH$, b.p. 36°, $D_{29} = 1{\cdot}213$, is produced when zinc and hydrochloric acid act on cacodyl chloride in alcoholic solution. It is a colourless, mobile liquid, with the characteristic cacodyl odour, and inflames spontaneously in the air. It combines with acids to form very easily dissociated salts; the halogen acid salts decompose into hydrogen and cacodyl chloride, bromide or iodide. With iodoalkyls it forms tetraalkyl arsonium iodides. It unites with sulphur, producing *cacodyl disulphide*, $[(CH_3)_2As]_2S_2$, m.p. 50°, and *cacodyl sulphide*, $[(CH_3)_2As]_2S$, b.p. 211°. Oxidation produces cacodyl, cacodyl oxide, cacodylic acid, As_2O_3, CO_2, etc., according to the degree of action (B. **27**, 1378; C. 1906, I. 738).

Cacodyl Chloride, $As(CH_3)_2Cl$, b.p. 100°, is formed by heating trimethylarsine dichloride, $As(CH_3)_3Cl_2$ (p. 177), and by acting on cacodyl oxide with hydrochloric acid, as well as from Cl_2 and cacodyl. It is more readily obtained by heating the mercuric chloride compound of the oxide with hydrochloric acid. It unites with chlorine to form the *trichloride*, $As(CH_3)_2Cl_3$, which renders possible the transition from the dimethyl compounds to the monomethyl derivatives.

Cacodyl Cyanide, $As(CH_3)_2.CN$, m.p. 36°, b.p. 140°, is formed by heating cacodyl chloride with mercuric cyanide.

Cacodylic Acid, $(CH_3)_2AsO.OH$, m.p. 200° with decomposition, corresponds in its composition to dimethyl phosphinic acid (see p. 175). Cacodyl oxide, by slow oxidation, passes into cacodyl cacodylate, which breaks down, when distilled with water, into cacodylic oxide and cacodylic acid:



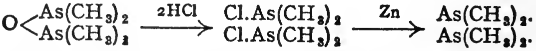
$$\begin{matrix}As(CH_3)_2\\As(CH_3)_2\end{matrix}\!>\!O+O = \begin{matrix}As(CH_3)_2\\OAs(CH_3)_2\end{matrix}\!>\!O.$$

$$2\begin{matrix}As(CH_3)_2\\OAs(CH_3)_2\end{matrix}\!\wedge\!O+H_2O = [As(CH_3)_2]_2O+2OAs(CH_3)_2.OH.$$

It is also obtained by the action of mercuric oxide on cacodylic oxide. On the formation of cacodylic acid from methyl arsenoxide, KOH, and iodomethane, see method of formation 4, p. 177.

It is easily soluble in water and is colourless. Like arrhenal (p. 177) it is employed pharmaceutically, but is more poisonous. Cacodylic acid forms salts with bases KdO_2Me and with acids KdOX—it is an amphoteric electrolyte (B. **37**, 2705, 3625, 4140). With H_2S it forms *Cacodyl Sulphide*, with HI *Cacodyl Iodide*, $(CH_3)_2AsI$. PCl_5 changes it to *Dimethyl Arsine Trichloride*, $(CH_3)_2AsCl_3$, from which water regenerates cacodylic acid.

Cacodyl, *Arsenic Dimethyl*, $As_2(CH_3)_4 = \begin{array}{l}As(CH_3)_2\\ | \\ As(CH_3)_2\end{array}$, m.p. −6°, b.p. 170°, is formed by heating the chloride with zinc filings in an atmosphere of carbon dioxide:



$$O\!<\!\begin{matrix}As(CH_3)_2\\As(CH_3)_2\end{matrix} \xrightarrow{2HCl} \begin{matrix}Cl.As(CH_3)_2\\Cl.As(CH_3)_2\end{matrix} \xrightarrow{Zn} \begin{matrix}As(CH_3)_2.\\As(CH_3)_2.\end{matrix}$$

It is a colourless liquid, insoluble in water. Its odour is powerful, and may induce vomiting. Cacodyl takes fire very readily in the air and burns to As_2O_3, carbon dioxide and water. It yields cacodyl chloride with chlorine, and the sulphide with sulphur. Nitric acid converts it into a nitrate, $As(CH_3)_2O.NO_2$.

Ethyl Cacodyl, $\begin{array}{l}As(C_2H_5)_2\\ | \\ As(C_2H_5)_2\end{array}$, b.p. 185–190°, is formed together with triethyl arsine on heating sodium arsenide with ethyl iodide. It takes fire in the air, and is converted by oxidation into *diethyl arsenic acid*, $(C_2H_5)_2AsO.OH$.

Diisoamyl Arsine Chloride, $(C_5H_{11})_2AsCl$, is produced from isoamyl chloride, arsenic trichloride, and sodium in ether. With H_2S it changes to *Diisoamyl Arsine Sulphide*, m.p. 30°; with bromine water it forms *Diisoamyl Arsinic Acid*, $(C_5H_{11})_2AsOOH$, m.p. 154° (C. 1906, I. 741). *Diisoamyl Arsine*, $(C_5H_{11})_2AsH$, b.p.$_{90}$ 150°, results from the reduction of diisoamyl arsinic acid; it is not spontaneously inflammable (C. 1906, I. 74).

TERTIARY ARSINES

The tertiary arsines are formed by the action of the zinc alkyls on arsenic trichloride, and by heating the alkyl iodides with sodium arsenide. Cacodyl, formed simultaneously, is separated by fractional distillation.

Trimethyl Arsine $(CH_3)_3As$, and *Triethyl Arsine*, $(C_2H_5)_3As$, are liquids with a very disagreeable odour. With oxygen they yield *Trimethyl Arsenoxide* $(CH_3)_3AsO$, and *Triethyl Arsenoxide*, $(C_2H_5)_3AsO$. These bodies correspond to *triethylamine oxide* (p. 172) and *triethyl phosphine oxide* (p. 173); with sulphur they yield *trimethyl* and *triethyl arsine sulphide*, $As(C_2H_5)_3S$; and with Br_2 and I_2 they form *trimethyl arsine bromide*, $As(CH_3)_3Br_2$, and *triethyl arsine iodide*, $As(C_2H_5)_3I_2$.

QUATERNARY ALKYL ARSONIUM COMPOUNDS

Tetra-alkylarsonium iodide is obtained (1) from mono-, di-, or tri-alkyl arsine by means of iodoalkyls; (2) from sodium arsenide, mercury arsenide, or powdered arsenic and iodoalkyls by the aid of heat (A. **341**, 182; C. 1907, I, 152). *Tetramethyl Arsonium Iodide*, $As(CH_3)_4I$, and *Tetraethyl Arsonium Iodide*, $As(C_2H_5)_4I$, m.p. of both indefinite, are stable, and are of good crystalline form. They correspond with the tetraalkyl ammonium and phosphonium iodides (pp. 163, 174). Like them they are changed by moist silver oxide into the hydrated oxides: *Tetramethyl Arsonium Hydroxide*, $(As(CH_3)_4OH$, and *Tetraethyl Arsonium Hydroxide*, $As(C_2H_5)_4OH$, are crystalline deliquescent bodies, possessing a strongly alkaline reaction.

8. ALKYL DERIVATIVES OF ANTIMONY

The derivatives of antimony and the alkyls are perfectly analogous to those of arsenic, but those containing one and two alkyl groups do not exist. We are indebted to *Löwig* and to *Landolt* for our knowledge of them.

Tertiary Stibines are produced like the tertiary arsines:

(1) by the action of alkyl iodides on potassium or sodium antimonides;

(2) by the interaction of zinc alkyls and antimony trichloride.

Trimethyl Stibine, $Sb(CH_3)_3$, b.p. 81°, $D_{15}=1{\cdot}523$, and *Triethyl Stibine*, $Sb(C_2H_5)_3$, b.p. 159°, are liquids which take fire in the air, and are insoluble in water. In all their reactions they exhibit the character of a bivalent metal, such as calcium or zinc. With oxygen, sulphur, and the halogens, they combine energetically, and even decompose concentrated hydrochloric acid:

$$Sb(C_2H_5)_3+2HCl=Sb(C_2H_5)_3Cl_2+H_2.$$

Triethyl Stibine Oxide, $Sb(C_2H_5)_3O$, is soluble in water, which is also true of *Triethyl Stibine Sulphide*, $Sb(C_2H_5)_3S$, which consists of shining crystals. Its solution behaves somewhat like a calcium sulphide solution. It precipitates sulphides from solutions of the heavy metals with the formation of salts of triethyl stibine. *Triethyl Stibine Chloride* is also prepared from antimony pentachloride and C_2H_5MgI. The *iodide*, m.p. 70° (B. **37**, 320).

Quaternary Stibonium Compounds, prepared from tertiary stibines by the addition of alkyl iodides, are changed by moist silver oxide into *tetra-alkyl stibonium hydroxides*. *Tetramethyl* and *Tetraethyl Stibonium Iodide*, $Sb(C_2H_5)_4I$, as well as *Tetramethyl* and *Tetraethyl Stibonium Hydroxide*, $(C_2H_5)_4SbOH$, greatly resemble the corresponding arsenic derivatives in their properties. For mercury double salts with tetra-alkyl stibonium halides, see C. 1900, I. 1091.

9. ALKYL COMPOUNDS OF BISMUTH

These are closely comparable with those derived from antimony and arsenic; but in accordance with the more metallic nature of bismuth, no compounds analogous to stibonium or arsonium are formed.

Further, in trialkyl derivatives the alkyl groups are less intimately united with the bismuth than they are with arsenic and antimony in their corresponding derivatives.

Tertiary Bismuthides result from (1) the action of alkyl iodides on potassium bismuthide; (2) the interaction of zinc alkyls and bismuth tribromide.

Bismuth Trimethyl, $Bi(CH_3)_3$, and *Bismuth Triethyl*, $Bi(C_2H_5)_3$, are liquids which can be distilled without decomposition under reduced pressure. They explode when heated at the ordinary pressure (B. **20**, 1516; **21**, 2035). Bismuth trimethide is changed by hydrochloric acid to $BiCl_3$ and *methane*. The tri-ethide is spontaneously inflammable. It unites with iodine to *Bismuth Diethyl Iodide*, $Bi(C_2H_5)_2I$; and reacts with mercuric chloride to form *Bismuth Ethyl Dichloride*, $Bi(C_2H_5)Cl_2$:

$$Bi(C_2H_5)_3+2HgCl_2=Bi(C_2H_5)Cl_2+2Hg(C_2H_5)Cl.$$

From the alcoholic solution of the iodide the alkalis precipitate *Bismuth Ethyl Oxide*, $Bi(C_2H_5)O$, an amorphous, yellow powder, which takes fire readily in the air. The *nitrate*, $Bi(C_2H_5)<\begin{matrix}O.NO_2\\O.NO_2\end{matrix}$, is produced by adding silver nitrate to the iodide.

10. ALKYL DERIVATIVES OF BORON

These are formed by the action of zinc alkyls on (1) boron trichloride, (2) boric ethyl ester (p. 141) (*Frankland*, A. **124**, 129):

$$2B(OC_2H_5)_3+3Zn(C_2H_5)_2=2B(C_2H_5)_3+3(C_2H_5.O)_2Zn.$$

Trimethyl Borine is a gas.

Triethyl Borine, $B(C_2H_5)_3$, b.p. 95°. Both ignite in contact with the air and possess an extremely penetrating odour. When heated together with hydrochloric acid, triethyl borine decomposes into diethyl borine chloride and ethane:

$$B(C_2H_5)_3+HCl=B(C_2H_5)_2Cl+C_2H_6.$$

Slowly oxidized in the air, triethyl borine passes into *Ethyl Boric Diethyl Ester*, $B(C_2H_5)(O.C_2H_5)_2$, b.p. 125°, which water decomposes into *Ethyl Boric Acid*, $C_2H_5.B(OH)_2$.

11. ALKYL DERIVATIVES OF SILICON

Silicon is the nearest analogue of carbon, to which its similarity is specially close in its derivatives with the alcohol radicals, which in many respects resemble the correspondingly constituted paraffins (*Friedel, Crafts; Ladenburg*, A. **203**, 241). As early as 1863 *Wöhler* directed attention to the analogy existing between the carbon and silicon compounds.

Silicon Tetramethyl, $Si(CH_3)_4$, corresponds with *Tetramethyl Methane*, $C(CH_3)_4$.

Silicon Tetraethyl, $Si(C_2H_5)_4$, corresponds with *Tetraethyl Methane*, $C(C_2H_5)_4$.

They are produced, like the alkyl borines, when zinc alkyls act on

(1) Silicon halogen compounds;

(2) Esters of silicic acid.

(3) Also, silicon tetrachloride and ethyl magnesium iodide or bromide in ether give rise to a number of bodies according to the quantity of the second reacting substance employed:

$$\underset{\text{Ethyl Silicon Trichloride.}}{C_2H_5SiCl_3} \longrightarrow \underset{\text{Diethyl Silicon Dichloride.}}{(C_2H_5)_2SiCl_2} \longrightarrow \underset{\text{Triethyl Silicon Chloride.}}{(C_2H_5)_3SiCl} \longrightarrow \underset{\text{Tetraethyl Silicon.}}{(C_2H_5)_4Si.}$$

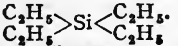
If ethyl silicon trichloride is acted on by other organo-magnesium halides, mixed alkyl silicon compounds can be obtained, *e.g.* $ClSi(C_2H_5)(C_6H_5)(C_3H_7)$ (C. 1904, I. 636; 1907, I. 1192).

(4) Silicon tetrachloride or silicon chloroform, chloro-alkyls, and sodium in ether react to form alkyl silicon compounds:

$$SiCl_4 + 4ClC_2H_5 + 8Na = Si(C_2H_5)_4 + 8NaCl.$$
$$HSiCl_3 + 3ClC_5H_{11} + 6Na = HSi(C_5H_{11})_3 + 6NaCl.$$

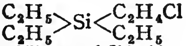
Silicon Tetramethyl, $Si(CH_3)_4$, b.p. 30°, $D_0 = 0{\cdot}928$, a liquid insoluble in water, is prepared from $SiCl_4$ and zinc methyl.

Silicon Tetraethyl, *Silicononane,* $Si(C_2H_5)_4$, b.p. 153°, $D_0 = 0{\cdot}834$, formed from $SiCl_4$ and $Zn(C_2H_5)_2$, or C_2H_5Cl and sodium, is a liquid insoluble in water. By the action of chlorine, it forms silicononyl chloride, a substitution product. Potassium acetate changes this to the acetic ester of silicononyl alcohol, which alkalis decompose into acetic acid and **silicononyl alcohol:**



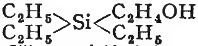
$$\frac{C_2H_5}{C_2H_5}{>}Si{<}\frac{C_2H_5}{C_2H_5}$$

Silicononane, b.p. 153°.



$$\frac{C_2H_5}{C_2H_5}{>}Si{<}\frac{C_2H_4Cl}{C_2H_5}$$

Silicononyl Chloride, b.p. 85°.



$$\frac{C_2H_5}{C_2H_5}{>}Si{<}\frac{C_2H_4OH}{C_2H_5}$$

Silicononyl Alcohol, b.p. 190°.

Silicon Tetraisoamyl, b.p. 275°. *Silicon Triisoamyl Hydride* $Si(C_5H_{11})_3H$, b.p. 245°, with bromine, passes into *Silicon Triamyl Bromide,* $Si(C_5H_{11})_3Br$, b.p. 279°, a heavy liquid, fuming in the air, which with ammonia gives *Triamyl Silicol,* $Si(C_5H_{11})_3OH$, b.p. 270° (B. **38**, 1665).

Disilicon Hexethyl, $Si_2(C_2H_5)_6$, b.p. 250–253°, is formed from zinc ethyl and Si_2I_6.

Triethyl Silicon Ethoxide, $(C_2H_5)_3SiOC_2H_5$, b.p. 153°.

Diethyl Silicon Diethoxide, $(C_2H_5)_2Si(OC_2H_5)_2$, b.p. 155·8°.

Ethyl Silicon Triethoxide, $(C_2H_5)Si(O.C_2H_5)_3$, b.p. 159°, is a liquid with a camphor-like odour. These three compounds are produced when zinc ethyl acts on silicic ethyl ester, $Si(OC_2H_5)_4$ (p. 141).

Acetic anhydride converts triethyl silicon ethoxide into an acetic ester. When this is hydrolyzed by potassium hydroxide, it yields *Triethyl Silicon Hydroxide* or *Triethyl Silicol,* $(C_2H_5)_3SiOH$, corresponding in constitution with *Triethyl Carbinol.*

Acetyl chloride changes diethyl silicon diethoxide into *Diethyl Silicon Chloride,* $(C_2H_5)_2SiCl_2$, b.p. 148°. Water converts this into *Diethyl Silicon Oxide,* $(C_2H_5)_2SiO$, corresponding with diethyl ketone in composition.

With acetyl chloride, ethyl silicon triethoxide forms *Ethyl Silicon Trichloride,* $(C_2H_5)SiCl_3$, b.p. about 100°. This liquid fumes strongly in the air, and when treated with water passes into ethyl silicic acid, $(C_2H_5)SiO.OH$ (silico-propionic acid), which is analogous to propionic acid, $C_2H_5.CO.OH$, in constitution. It is a white, amorphous powder, which becomes incandescent when heated in the air. It only resembles the corresponding propionic acid by being acidic in character.

$(C_2H_5)_3SiOH$,	Triethyl Silicol corresponds with $(C_2H_5)_3C.OH$, Triethyl Carbinol.
$(C_2H_5)_2SiO$,	Diethyl Silicon Oxide corresponds with $(C_2H_5)_2CO$, Diethyl Ketone.
$C_2H_5.SiOOH$,	Silico-propionic Acid corresponds with $C_2H_5.COOH$, Propionic Acid.

12. ALKYL DERIVATIVES OF GERMANIUM

The compounds of germanium form the transition from those of silicon to those of tin.

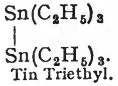
Germanium Ethyl, $Ge(C_2H_5)_4$, b.p. 160°, is formed when zinc ethyl acts on germanium chloride. It is a liquid with a leek-like odour. (*Cl. Winkler,* J. pr. Ch. [2] **36**, 204.)

13. TIN ALKYL COMPOUNDS

In addition to the saturated derivatives with four alkyls, tin is also capable of uniting with three and two alkyls, forming:

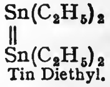
$Sn(C_2H_5)_4$.

Tin Tetraethyl.



$$\begin{array}{c}Sn(C_2H_5)_3\\ |\\ Sn(C_2H_5)_3.\end{array}$$

Tin Triethyl.



$$\begin{array}{c}Sn(C_2H_5)_2\\ \|\\ Sn(C_2H_5)_2\end{array}$$

or $Sn(G_2H_5)_2$.

Tin Diethyl.

The alkyl derivatives of tin were studied by *Löwig*, *Cahours*, *Ladenburg*, and others. The reactions employed to cause the combination of tin with alkyls are the same as were employed in the cases of arsenic, antimony, and other elements. (1) The action of zinc alkyls on stannic chloride, whereby $Sn(CH_3)_4$ and $Sn(C_2H_5)_4$ are produced (B. **37**, 320; C. 1904, I. 353). (2) The action of alkyl iodides on tin-sodium (tin alone or tin-zinc). When the alloy contains a great deal of sodium, $Sn(C_2H_5)_2I_2$ is produced, but when comparatively little sodium is present the chief product is $Sn(C_2H_5)_3I$. Sodium abstracts iodine from both of the primarily formed iodides with the formation of $Sn_2(C_2H_5)_4$ and $Sn_2(C_2H_5)_6$. These can be separated by means of alcohol, in which the latter is insoluble.

Tin Tetramethyl, $Sn(CH_3)_4$, b.p. 78°, and **Tin Tetraethyl,** $Sn(C_2H_5)_4$, b.p. 181°, $D_{23}=1{\cdot}187$; both are colourless, ethereal smelling liquids, insoluble in water. By the action of the halogens the alkyls are successively eliminated; hydrochloric acid acts similarly:

$$Sn(C_2H_5)_4+I_2=Sn(C_2H_5)_3I+C_2H_5I, \text{ etc.}$$
$$Sn(C_2H_5)_4+HCl=Sn(C_2H_5)_3Cl+2C_2H_6, \text{ etc.}$$

(For tin tetra-alkyls with different alkyl groups see C. 1904, I. 353.)

The alkyl groups are not so firmly united in the zinc alkyls as they are in the alkyls of silicon.

Tin Triethyl Chloride, $Sn(C_2H_5)_3Cl$, b.p. 208–210°, $D=1{\cdot}428$. *Tin Triethyl Iodide*, $Sn(C_2H_5)_3$,I, b.p. 231°, $D_{22}=1{\cdot}833$. Alcohol and ether are solvents for both. When either is acted on by silver oxide or potassium hydroxide, there is produced:

Tin Triethyl Hydroxide, $Sn(C_2H_5)_3.OH$, m.p. 66°, b.p. 272°, is sparingly soluble in water, but dissolves readily in alcohol and ether. It reacts strongly alkaline, and yields crystalline salts with the acids, *e.g.* $Sn(C_2H_5)_3.O.NO_2$. When the hydroxide is heated for some time to almost boiling temperature, it breaks down into water and *Tin Triethyl Oxide*, $\begin{matrix}Sn(C_2H_5)_3\\Sn(C_2H_5)_3\end{matrix}{>}O$, an oily liquid, which in the presence of water at once regenerates the hydroxide.

Tin Triethyl, $Sn_2(C_2H_5)_6$, b.p. 265–270°, with slight decomposition (see above), is a liquid, of mustard-like odour, insoluble in alcohol, but readily soluble in ether. It combines with oxygen, forming tin triethyl oxide, $\begin{matrix}Sn(C_2H_5)_2\\Sn(C_2H_5)_3\end{matrix}{>}O$, and with iodine yields tin triethyl iodide, $Sn(C_2H_5)_3I$.

Tin Diethyl, $Sn_2(C_2H_5)_4$, or $Sn(C_2H_5)_2$, is a thick oil, decomposing when heated into $Sn(C_2H_5)_4$ and tin. It combines with oxygen and the halogens.

Tin Diethyl Chloride, $Sn(C_2H_5)_2Cl_2$, m.p. 85°, b.p. 220°: *iodide*, $Sn(C_2H_5)_2I_2$, m.p. 44·5°, b.p. 245°.

Ammonium hydroxide and the alkalis precipitate from aqueous solutions of both the halogen compounds:

Tin Diethyl Oxide, $Sn(C_2H_5H)_2O$, a white, insoluble powder. It is soluble in excess of alkali, and forms crystalline salts with the acids, *e.g.* $Sn(C_2H_5)_2(ONO_2)_2$.

Methyl Stannonic Acid, CH_3SnOOH, is formed at ordinary temperatures from iodomethane and an alcoholic solution of an alkaline stannous solution similarly to the preparation of methyl sulphonic acid and methyl arsenic acid (pp. 146, 177) from iodoethane and an alkaline solution of sulphurous and arsenious acids:

$$ICH_3+HSnO_2K+KOH=CH_3SnO_2K+KI+H_2O.$$

Methyl stannonic acid is a white amorphous powder, soluble in potassium hydroxide solution, from which it is precipitated by CO_2. Warming with alkalis produces stannates and *Dimethyl Stannic Oxide*, which by distillation with alkalis decomposes into stannates and *Trimethyl Stannic Hydroxide :*

$$2CH_3SnO_2K \longrightarrow SnO_3K_2+(CH_3)_2SnO.$$
$$3(CH_3)_2SnO \xrightarrow{2KOH} 2(CH_3)_3SnOH+K_2SO_3.$$

Similarly, *Ethyl Stannonic Acid* yields *Diethyl Stannic Oxide*.

Methyl stannonic acid is transformed by the halogen acids into *Methyl Stannic Triiodide*, CH_3SnI_3, m.p. 86°, *Methyl Stannic Tribromide*, CH_3SnBr_3, m.p. 53°, and *Methyl Stannic Trichloride*, CH_3SnCl_3, m.p. 43°, which fume in the air like tin tetrachloride. Thus, methyl stannonic acid behaves like cacodylic acid, as an amphoteric electrolyte. Methyl stannic triodide can also be obtained from stannous iodide and iodomethane at 160° ; from stannic iodide and magnesium methyl-iodide together with *Trimethyl Stannic Iodide*, $(CH_3)_3Sn$, b.p. 170° (B. **36**, 3027 ; **37**, 4618) ; and by heating together tin tetramethyl and stannic iodide (C. 1903, II. 106).

14. METALLO-ORGANIC COMPOUNDS

The metallo-organic compounds are those resulting from the union of metals with univalent alkyls ; those with the bivalent alkylens, C_nH_{2n}, have not yet been prepared. Inasmuch as we have no marked line of difference between metals and non-metals, the metallo-organic derivatives are connected, in the one direction, through the derivatives of antimony and arsenic, with phosphorus and nitrogen bases ; and in the other, through the selenium and tellurium compounds, with the sulphur alkyls and ethers ; whereas the lead derivatives approach those of tin, and the latter the silicon alkyls and the hydrocarbons.

Upon examining the metals as they arrange themselves in the periodic system it is rather remarkable to find that it is only those which attach themselves to the electronegative non-metals that are capable of yielding alkyl derivatives. In the three large periods this power manifests and extends itself only as far as the group of zinc (Zn, Cd, Hg). (Comp. *Inorganic Chemistry*.)

In a sense the metallic carbides, C_2Na_2, C_2Ca, C_3Al_4 (pp. 67, 88) can also be looked on as being metallo-organic compounds.

Those compounds in which the metals present their maximum valence, *e.g.* :

$$\overset{\text{II}}{Hg}(CH_3)_2 \qquad \overset{\text{III}}{Al}(CH_3)_3 \qquad \overset{\text{IV}}{Sn}(CH_3)_4 \qquad \overset{\text{IV}}{Pb}(CH_3)_4$$

are volatile liquids, usually distilling without decomposition in vapour form ; therefore, the determination of their vapour density is an accurate means of establishing their molecular weight, and the valence of the metals.

The behaviour of the metallo-organic radicals, derived from the molecules by the loss of single alkyl groups, is especially noteworthy. The univalent radicals, *e.g.* :

$$-\overset{\text{II}}{Hg}(CH_3) \quad -\overset{\text{III}}{Tl}(CH_3)_2 \quad -\overset{\text{IV}}{Sn}(CH_3)_3 \quad -\overset{\text{IV}}{Pb}(CH_3)_3 \quad -\overset{\text{V}}{Sb}(CH_3)_4,$$

show great resemblance to the alkali metals in all their derivatives. Like other univalent radicals, they cannot be isolated. They yield hydroxides, *e.g.* :

$$Hg(C_2H_5).OH \qquad Tl(CH_3)_2.OH \qquad Sn(CH_3)_3.OH,$$

which are perfectly comparable to KOH and NaOH. Some of the univalent radicals, when set free from their compounds, become doubled:

$$\begin{array}{cccc} As(CH_3)_2 & Si(CH_3)_3 & Sn(CH_3)_3 & Pb(CH_3)_3 \\ | & | & | & | \\ As(CH_3)_2 & Si(CH_3)_3 & Sn(CH_3)_3 & Pb(CH_3)_3. \end{array}$$

By the loss of two alkyls from the saturated compounds, the divalent radicals result:

$$=\overset{III}{Bi}(CH_3) \qquad =\overset{IV}{Te}(CH_3)_2 \qquad =\overset{IV}{Sn}(C_2H_5)_2 \qquad =\overset{V}{Sb}(CH_3)_3.$$

In their compounds (oxides and salts) these resemble the divalent alkali earth metals, or the metals of the zinc group. A few of them occur in the free condition. As unsaturated molecules, however, they show strong inclination to saturate two single affinities directly. Antimony triethyl, $Sb(C_2H_5)_3$ (see p. 179), and apparently, also, tellurium diethyl, $Te(C_2H_5)_2$, have the power of uniting with acids to form salts, liberating hydrogen at the same time. This would indicate a distinct metallic character.

Finally, the travilent radicals, like $\equiv As(CH_3)_2$, can also figure as univalent, as in the case of vinyl, C_2H_3. These may be compared to aluminium; and cacodylic acid, $As(CH_3)_2O.OH$ (p. 178), to aluminium metahydroxide, AlO.OH.

We conclude, therefore, that the electro-negative metals, by the successive union of alcohol radicals, always acquire a more strongly basic, alkaline character. This also finds expression with the non-metals (sulphur, phosphorus, arsenic, etc.). (Comp. pp. 145, 173, 175.)

The first metallo-organic derivatives were prepared by *Frankland*. *Zinc alkyls* are particularly important as alkylating bodies, but are being replaced by *magnesium alkyl halides*, which are much more convenient to work with.

Methods of Formation:

(1) Action of metals (Mg, Zn, Hg) on alkyl iodides.

(2) Action of alloys (Pb, Na) on alkyl iodides (see Bi-, Sb-, Sn-compounds).

(3) Action of metals (K, Na, Be, Al) on metallo-organic bodies (zinc alkyls, mercury alkyls).

(4) Action of metallic chlorides ($PbCl_2$) on metallo-organic derivatives (zinc alkyls or magnesium alkyl halides; comp. BCl_3, $SiCl_4$, $SnCl_4$, $GeCl_4$ on zinc alkyls or magnesium alkyl halides).

A. ALKYL DERIVATIVES OF THE ALKALI METALS

When sodium or potassium is added to zinc methyl or ethyl, zinc separates at the ordinary temperature, and from the solution which is thus produced, crystalline compounds deposit on cooling. The liquid retains a great deal of unaltered zinc alkyl, but it also appears to contain the sodium and potassium compounds—at least it sometimes reacts quite differently from the zinc alkyls. Thus, it absorbs carbon dioxide, forming salts of the fatty acids (*Wanklyn*, A. **111**, 234):

$$C_2H_5Na + CO_2 = \underset{\text{Sodium Propionate.}}{C_2H_5.CO_2Na.}$$

These decomposable bodies cannot be separated in a pure condition.

B. ALKYL DERIVATIVES OF THE MAGNESIUM GROUP

Beryllium Ethyl, $Be(C_2H_5)_2$, b.p. 185–188°, formed by the 3d method, ignites spontaneously. *Beryllium Propyl*, $Be(C_3H_7)_2$, b.p. at 245°.

Magnesium Dimethyl, $Mg(CH_3)_2$ and *Magnesium Diethyl*, $Mg(C_2H_5)_2$, result from the action of Mg on the corresponding mercury compounds. They are white, solid, substances, which inflame spontaneously even in a CO_2 atmosphere, and are decomposed by heat, evolving hydrocarbons. They react with water like the zinc alkyls (A. **276**, 129).

Magnesium Alkyl Halides.—Whilst the magnesium alkyls are troublesome to prepare and to manipulate, the preparation of the magnesium alkyl halides is exceedingly easy and convenient, especially in solution. The metal is dissolved in a solution of the alkyl halide in absolute ether, and the reagent is ready for use:

$$C_2H_5Br+Mg=C_2H_5MgBr.$$

The general applicability of this reaction was first recognized by the French chemist *Grignard*,* whose name is associated with the reaction and solution. In a short time it was employed by a large number of investigators, and has become an invaluable agent in organic synethesis.

The reaction proceeds most quickly in the case of alkyl iodides and bromides; whilst methyl and ethyl chlorides require assistance to react in the form of an addition of iodine (B. **38**, 2759) $HgCl_2$ (C. 1907, I. 872) or a previously prepared magnesium solution (B. **38**, 1746; C. 1907, I. 455). Alkyl halides behave similarly to the alkyl halides (B. **36**, 2898). Sometimes the reaction proceeds abnormally, splitting off halogen acids, as in the case of isopropyl iodide, and especially tertiary alkyl halides; at low temperatures, however, the normal reaction takes place (C. 1904, I. 644; II. 183). It is of importance that the haloid aryls, such as iodo- and bromo-benzene react analogously to the alkyl halides (Vol. II.).

Distillation of the solvent ether leaves the magnesium alkyl halides behind usually in the form of crystalline "etherates," $RMgI.O(C_2H_5)_2$, $RMgI.2O(C_2H_5)_2$, which dissolve easily in ether, benzene, etc. If these double compounds are decomposed in vacuo at raised temperatures, a greyish white mass remains; it is insoluble in ether, it becomes hot in contact with the air, and decomposes violently in water. The ether apparently acts as a catalyzer in the *Grignard* solution; its action is weakened when other solvents, especially chloroform, carbon disulphide, etc., are employed (C. 1906, I. 130; II. 1718). Similarly to ether, the tertiary amines, *e.g.* dimethylamine, also act catalytically, and these also form double compounds with the magnesium alkyl halides, such as $R'MgXNR_3$ (B. **37**, 3088; C. 1904, II. 836). The addition of a few drops of dimethyl aniline to a benzene solution of iodoethane, for example, causes the production of pure *Ethyl Magnesium Iodide* by the action of magnesium, in the form of a white powder. This reacts analogously to the "etherates" and dissolves in ether, with an evolution of heat, to form these bodies (B. **38**, 4534; **39**, 1674).

The ethereal solutions of the magnesium alkyl halides are very reactive and exhibit similar reactions to those of the zinc alkyls, which, however, usually run more smoothly (p. 186):

(1) Water, alcohols, ammonia, primary, and secondary amines, bring about a more or less violent decomposition, causing the generation of hydrocarbons:

$$C_2H_5MgI+ROH=C_2H_6+ROMgI; \quad C_2H_5MgI+RNH_2=C_2H_6+RNHMgI.$$

Acetylene and hydrocyanic acid behave similarly.

(2) Oxygen and sulphur are absorbed, and alcoholates and mercaptides result:

$$RMgX+O \longrightarrow ROMgX; \quad RMgX+S=RSMgX.$$

(3) CO_2, COS, CS_2, SO_2, are taken up, forming salts of carboxylic acids, thiocarbonic acids, carbithionic acids, sulphinic acids, *e.g.*:

$$C_2H_5MgI+CO_2=C_2H_5COOMgI.$$

NO_2 forms salts of the β-dialkyl hydroxylamines (p. 171) and NO those of the β-nitroso-alkyl hydroxylamines (p. 172).

Salts of the diazo-amino bodies result from hydrazoic esters.

(4) Aldehydes, ketones, carboxylic acid esters, anhydrides, chlorides and salts yield primary, secondary, and, especially easily, tertiary *alcohols* (pp. 106, 108).

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* "Sur les combinaisons organomagnésiennes mixtes et leurs applications à des synthèses," Lyon, 1901. See also "Ueber die organischen Magnesiumverbindungen und ihre Anwendung zu Synthesen," J. Schmidt, Stuttgart, 1905.

Many of these tertiary alcohols give up water yielding olefines, especially in presence of an excess of RMgX; *e.g.* diolefines (p. 90), etc.

Ethylene oxide and its homologues unite with the magnesium alkyl halides to form alcohols (p. 106).

Formic acid derivatives, such as esters, orthoesters, imido ethers, dialkylamides, isonitriles, under suitable conditions, yield aldehydes.

Carboxylic acid amides and nitriles frequently give rise to *ketones.*

The magnesium alkyl halides are added on to many $\alpha\beta$-olefine ketones, carboxylic acid esters, and nitriles at the double bond, forming the corresponding β-alkyl paraffin compounds (C. 1907, I. 559, etc.).

With *Schiff's* base, RCH:NR′, they form secondary amines, RR″CH.NHR′. Often these bodies, ketones, and other substances are only reduced by the organo-magnesium halides (B. **38**, 2716; C. 1906, II, 312).

Iodine changes the magnesium alkyl chlorides and bromides to alkyl iodides (p. 133).

(6) Halogen or sulphuric acid compounds of many radicals have the haloid or sulphuric acid residues replaced by alkyl, *e.g.:*

$$C_5H_{11}MgBr + BrCH_2OCH_3 \longrightarrow C_5H_{11}CH_2OCH_3.$$
$$C_5H_{11}MgBr + SO_4(CH_3)_2 \longrightarrow C_5H_{11}.CH_3.$$

By similar reactions for the preparation of isoamyl and isohexyl magnesium bromides, diisoamyl and diisohexyl are formed as by-products (p. 76) (B. **36**, 3084).

(7) On the formation of alkyl compounds of phosphorus, arsenic, antimony, silicon, tin, lead, and thallium from organo-magnesium halides, and the chlorides of these metals and metalloids, see the previous and following sections.

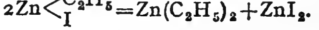
Calcium Ethyl Iodide is prepared similarly to the magnesium compound from calcium and iodoethane in ether solution. It forms an "etherate," $C_2H_5CaI.O(C_2H_5)_2$ which is a white amorphous powder, soluble with difficulty in ether. It generates ethane when acted on by water (B. **38**, 905).

C. ALKYL DERIVATIVES OF ZINC

Zinc methyl and zinc ethyl were discovered in 1849 by *Frankland* (A. **71**, 213; **85**, 329; **99**, 342). The zinc alkyls are exceedingly reactive, and are, on this account, the most important class of the metallic alkyls.

Methods of Formation.—(1) When zinc filings act on iodides of the alcohol radicals in sunlight, iodides are formed, which are decomposed by heat into zinc alkyls and zinc iodide:

$$C_2H_5I + Zn = IZnC_2H_5.$$



$$2Zn{<}\genfrac{}{}{0pt}{}{C_2H_5}{I} = Zn(C_2H_5)_2 + ZnI_2.$$

The action may be accelerated if the zinc turnings have been previously corroded, or by the application of zinc-sodium or zinc-copper. In preparing zinc ethyl, ethyl iodide is poured over zinc cuttings and a little pure zinc ethyl is then added. The formation of $IZn.C_2H_5$ is then completed at the ordinary temperature, and this body separates in large, transparent crystals. When it is heated in a current of CO_2, it yields zinc ethyl (A. **152**, 220; B. **26**, R. 88; C. 1900, II. 460). It is also formed by the solution of zinc in a boiling ether solution of iodoethane (C. 1901, II. 24).

(2) The mercury alkyls are converted by zinc into zinc alkyls, with the separation of mercury:

$$Hg(C_2H_5)_2 + Zn = Zn(C_2H_5)_2 + Hg.$$

Properties.—The zinc alkyls are colourless, disagreeable-smelling liquids, fuming strongly in the air and igniting readily; therefore, they can only be handled in an atmosphere of carbon dioxide. They inflict painful wounds when brought into contact with the skin.

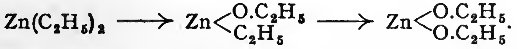
Zinc Methyl, $Zn(CH_3)_2$, b.p. 46°; $D_{10}=1{\cdot}386$, and
Zinc Ethyl, $Zn(C_2H_5)_2$, b.p. 118°; $D_{18}=1{\cdot}182$, both solidify when cooled (B. **261**, 59).
Zinc Propyl, $Zn(CH_2CH_2CH_3)_2$, b.p. 146°.
Zinc Isopropyl, $Zn(C_3H_7)_2$, b.p. 136° (B. **26**, R. 380).
Zinc Isobutyl, $Zn(C_4H_9)_2$, b.p. 166° (A. **223**, 168).
Zinc Isoamyl, $Zn(C_5H_{11})_2$, b.p. 210° (A. **130**, 122).

Reactions.—The zinc alkyls are exceedingly reactive.

(1) Water decomposes them very energetically, forming hydrocarbons and zinc hydroxide (see Methane, Ethane, pp. 71, 72).

(2) Oxygen is taken up by slow oxidation in the air, and compounds, *e.g.* $(CH_3)_2ZnO_2$, analogous to peroxides, are produced; they explode readily and liberate iodine from potassium iodide (B. **23**, 394).

(3) The alcohols convert the zinc alkyls into zinc alcoholates and hydrocarbons, depending on the relative quantities of the reacting bodies, *e.g.* ethyl zinc ethoxide, or zinc alcoholate may be formed, together with ethane (C. 1901, II. 1200).



$$Zn(C_2H_5)_2 \longrightarrow Zn{<}\begin{matrix}O.C_2H_5\\C_2H_5\end{matrix} \longrightarrow Zn{<}\begin{matrix}O.C_2H_5\\O.C_2H_5\end{matrix}.$$

(4) The free halogens decompose both the zinc alkyls and those of other metals very energetically:

$$Zn(C_2H_5)_2+2Br_2=2C_2H_5Br+ZnBr_2.$$

(5) They react with chlorides of the heavy metals and the non-metals, whereby alkyl derivatives of the latter are produced (p. 184).

(6) The zinc alkyls absorb sulphur dioxide and are converted into the zinc salts of the sulphinic acids (p. 147).

(7) Nitric oxide and zinc diethyl produce the zinc salt of the so-called *dinitroethylic acid*, $C_2H_5.N_2O_2H$.

The application of the zinc alkyls—zinc methyl and zinc ethyl—is particularly important in nucleus-synthetic reactions:

(1) Hydrocarbons are formed when the alkyl iodides are exposed to high temperatures (p. 75).

(2) When zinc alkyls (zinc and alkyl iodides) act on aldehydes, acid chlorides, acid anhydrides (C. 1901, II. 188), ketones, formic esters, acetic esters, lactones, and chlorinated ethers, derivatives of *secondary*, *tertiary*, and *primary* alcohols, as well as of *ketones*, are produced. The alcohols (pp. 105, 106) and ketones (p. 217) can easily be obtained from them.

The alkyl oxides and the alkylene oxides are, however, not affected by the zinc alkyls (B. **17**, 1968; C. 1901, II. 188), but, on the other hand, the heating together of ethylene oxide and magnesium halides is a method of synthesis of the primary alcohols (p. 186).

D. ALKYL DERIVATIVES OF CADMIUM

Cadmium Ethyl, $Cd(CH_3)_2$, b.p. 104°, is prepared in very small quantities by heating the product of reaction of cadmium and iodomethane. It solidifies in a freezing mixture. Its properties closely resemble those of zinc methyl.

E. ALKYL DERIVATIVES OF MERCURY

The **dialkyl compounds** are formed—

(1) by the interaction of sodium amalgam and alkyl iodides, with the addition of acetic ester (*Frankland*, A. **130**, 105, 109). The rôle of the acetic ester in this reaction has not yet been explained:

$$2C_2H_5I+Hg.Na_2=(C_2H_5)_2Hg+2NaI.$$

(2) by the action of potassium cyanide on mercury alkyl iodides;
(3) by the action of zinc alkyls on mercury alkyl iodides:

$$2C_2H_5HgI+Zn(C_2H_5)_2=2(C_2H_5)_2Hg+ZnI_2.$$

(4) by the action of zinc alkyls on mercuric chloride:

$$HgCl_2+Zn(C_2H_5)_2=(C_2H_5)_2Hg+ZnCl_2.$$

Properties.—These compounds are colourless, heavy liquids, possessing a faint, peculiar odour. Their vapours are extremely poisonous. Water and air occasion no change in them, but when heated they ignite easily.

Mercury Methyl, $Hg(CH_3)_2$, b.p. 95°, D=3·069. *Mercury Ethyl*, $Hg(C_2H_5)_2$, b.p. 159°, D=2·44, and at 200° breaks down into Hg and butane, $C_2H_5.C_2H_5$. It yields ethane (p. 73) when treated with concentrated sulphuric acid.

Mercury sec.-Butyl, $Hg[CH(CH_3)(C_2H_5)]_2$, b.p.$_{18}$ 91–93°, is prepared by electrolytic reduction of methyl ethyl ketone in sulphuric acid solution at 50° with a mercury cathode (B. **39**, 3626).

$$2C_4H_8O+Hg+6H=Hg(C_4H_9)_2+2H_2O.$$

The **mono-alkyl derivatives** arise (1) by the action of mercury on alkyl iodides in sunlight; $C_2H_5I+Hg=C_2H_5.Hg.I$; (2) from the dialkyl mercury derivatives —(*a*) by the action of halogens; (*b*) by the action of the halogen acids; (*c*) by the action of mercuric chloride.

Mercury Methyl Iodide, CH_3HgI, m.p. 143°, forms shining needles, and is insoluble in water. Silver nitrate changes it to *methyl mercury nitrate*, $CH_3Hg.ONO_2$. *Mercury Ethyl Iodide*, C_2H_5HgI, is decomposed, by sunlight, into mercuric iodide and C_4H_{10}. *Mercury Allyl Iodide*, C_3H_5HgI, m.p. 135°, is converted by HI into propylene and mercuric iodide, HgI_2. Moist silver oxide changes the haloid derivatives to *hydroxyl compounds:*

$$C_2H_5HgCl+AgOH=C_2H_5.Hg.OH+AgCl.$$

Ethyl Mercuric Hydroxide, C_2H_5HgOH, is a thick liquid, soluble in water and in alcohol. It reacts strongly alkaline, and forms salts with acids.

Mercury compounds, derivable from glycol, result from the action of ethylene on mercuric salts (B. **34**, 2910).

F. ALKYL DERIVATIVES OF THE METALS OF THE ALUMINIUM GROUP

The aluminium alkyl derivatives are comparable to those of boron (p. 180). They are produced by the action of the mercury alkyls upon aluminium filings.

Aluminium Trimethyl, $Al(CH_3)_3$, b.p. 130°. *Aluminium Triethyl*, $Al(C_2H_5)_3$, b.p. 194°. Both are colourless liquids and are spontaneously inflammable. Water decomposes them with great violence, forming methane (or ethane) and aluminium hydroxide. Their vapour densities indicate a mono- rather than a di- molecular constitution (see B. **22**, 551; Z. phys. Ch. **8**, 164).

The derivatives of trivalent *gallium* and *indium* have not been prepared.

Thallium Dimethyl Chloride, Bromide and Iodide $(CH_3)_2TlX$, as well as *Thallium Diethyl Chloride, Bromide, and Iodide*, and *Thallium Dipropyl Chloride, Bromide, and Iodide*, are prepared by the interaction of thallium chloride, $TlCl_3$, and magnesium alkyl halides in ether solution (p. 185). They are crystalline bodies, dissolving in water with great difficulty, and decomposing on being subjected to heat. They can be recrystallized from an alkaline aqueous solution without decomposition; moist silver oxide produces strongly alkaline, easily soluble hydroxides, *e.g. Thallium Diethyl Hydroxide*, $Tl(C_2H_5)_2OH$, which absorb CO_2 from the atmosphere and precipitate hydroxides from solutions of the metals, thus resembling thallous hydroxide TlOH (B. **37**, 2051).

G. ALKYL DERIVATIVES OF LEAD

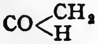
These are very similar to the derivatives of tin (p. 182), but those containing two alkyl groups combined with one atom of lead do not exist. In these the lead, as in most of its inorganic derivatives, would be bivalent. Lead alkyls are produced (1) by acting on lead chloride with zinc ethyl or magnesium ethyl iodide (B. **37**, 1127): $Pb(C_2H_5)_4$; (2) by the interaction of alkyl iodides and lead-sodium: $Pb_2(C_2H_5)_6$.

Lead Tetramethide, $Pb(CH_3)_4$, b.p. 110°. *Lead Tetraethide*, $Pb(C_2H_5)_4$, and *Lead Triethide*, $Pb_2(C_2H_5)_6$, are oily liquids which cannot be distilled without decomposition. *Lead Triethyl Chloride*, $Pb(C_2H_5)_3Cl$, and *Lead Triethyl Iodide*, $Pb(C_2H_5)_3I$, are prepared from lead tetraethyl and triethyl by hydrochloric acid or iodine. The iodide is transformed by moist silver oxide into a thick strongly alkaline liquid, dissolving with difficulty in water and forming salts with acids. *Lead Triethyl Sulphate*, $[Pb(C_2H_5)_3]_2SO_4$, is slightly soluble in water.

2. ALDEHYDES AND 3. KETONES

When the derivatives of the methane hydrocarbons containing oxygen were discussed, attention was directed to the intimate genetic relations existing on the one hand between the primary alcohols, the aldehydes and mono-carboxylic acids, and on the other between the secondary alcohols and the ketones (p. 100).

Aldehydes and ketones contain the carbonyl group CO, which in the latter unites with two alkyl groups, but in the former is combined with only one alkyl and one hydrogen atom:



$$CO<\begin{matrix}CH_3\\H\end{matrix}$$

Aldehyde.

$$CO<\begin{matrix}CH_3\\CH_3\end{matrix}$$

Dimethyl Ketone.

This expresses the similarity and the difference in character of aldehydes and ketones.

Aldehydes and ketones may be considered as the oxides of bivalent radicals, or as the anhydrides of *dihydroxy alcohols*, or *glycols*, in which both hydroxyl groups are attached to the same terminal or intermediate carbon atom. Whenever the formation of dihydroxyl derivatives of the type $>C<\begin{matrix}O-H\\O-H\end{matrix}$ might be expected, then, except in very rare instances, water separates, an *anhydride* is produced, and double union between carbon and oxygen follows, with the production of the carbonyl group $>C=O$. Ethers, however, of dihydroxy alcohols, of the *ortho-aldehydes* and *ortho-ketones*, can exist, *e.g.*:

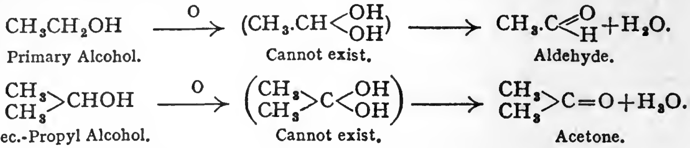
$$CH_3.CH(O.C_2H_5)_2 \quad \text{and} \quad CH_3.C(O.C_2H_5)_2.CH_3.$$

The three classes of alcohols (p. 102) are differentiated from each other by the words primary, secondary, and tertiary; the oxidation products, however, of the first two have received special names—aldehyde and ketone—although they are no more different from each other than their respective parent alcohols. A practical and excellent nomenclature would have been *primary* and *secondary aldehydes*, for then the name aldehyde, derived by *Liebig* from *alcohol dehydrogenatus* (p. 199), would have applied to both. The complete difference in the designation of aldehyde and ketone leads to the separate description of the formation and reactions of the two classes of bodies (*Anschütz*).

The following principal methods of formation are common to aldehydes and ketones:

(1) Oxidation of the alcohols, whereby the primary alcohols change to aldehydes and the secondary to ketones (p. 103).

In this oxidation an oxygen atom enters the molecule between a hydrogen atom and the carbon atom to which the hydroxyl group is joined. In the moment of formation the expected hydroxy alcohol splits off water, and its anhydride results,—an aldehyde or ketone:



$$CH_3CH_2OH \xrightarrow{O} \left(CH_3.CH{<}^{OH}_{OH}\right) \longrightarrow CH_3.C{\ll}^{O}_{H}+H_2O.$$

Primary Alcohol. Cannot exist. Aldehyde.

$${}^{CH_3}_{CH_3}{>}CHOH \xrightarrow{O} \left({}^{CH_3}_{CH_3}{>}C{<}^{OH}_{OH}\right) \longrightarrow {}^{CH_3}_{CH_3}{>}C{=}O+H_2O.$$

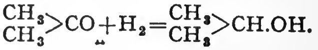
Sec.-Propyl Alcohol. Cannot exist. Acetone.

By further oxidation the aldehydes become changed into acids—*the hydrides of the acid radicals,*—whilst the ketones are decomposed.

Conversely, aldehydes and ketones are reconverted into primary and secondary alcohols by an addition of hydrogen:

$$CH_3.CHO+H_2=CH_3.CH_2.OH.$$

Aldehyde. Ethyl Alcohol.

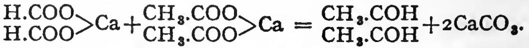


$${}^{CH_3}_{CH_3}{>}CO+H_2={}^{CH_3}_{CH_3}{>}CH.OH.$$

Aceto e. Isopropyl Alcohol.

Because the aldehydes and ketones manifest an additive power with reference to hydrogen, they may be compared with compounds containing doubly linked carbon atoms, which also, by a dissolution of their double union, can add hydrogen. Compounds of this class having in their molecules carbon atoms which are doubly or trebly united, are in the more restricted sense called "*unsaturated carbon derivatives*" (p. 69). This idea may be extended, and all carbon derivatives having atoms of other elements in double or treble union with carbon, may be considered as "*unsaturated.*" From this standpoint the aldehydes and ketones are unsaturated bodies (p. 23), and in fact most of the reactions of these two classes are due to the additive power of the unsaturated carbonyl group.

(2) The dry distillation of a mixture of the calcium, or better, barium salts of two monobasic fatty acids produces aldehydes or ketones according as one of the acids be formic acid or not.

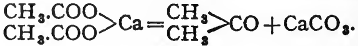


$${}^{H.COO}_{H.COO}{>}Ca+{}^{CH_3.COO}_{CH_3.COO}{>}Ca = {}^{CH_3.COH}_{CH_3.COH}+2CaCO_3.$$

Calcium Formate. Calcium Acetate. Acetaldehyde.

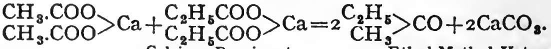
It is the hydrogen of the formate which reduces the acid, whereby an aldehyde results.

In all other instances ketones result, and they are either *simple,* with two similar alkyl groups, or *mixed,* with two dissimilar alkyls:



$${}^{CH_3.COO}_{CH_3.COO}{>}Ca={}^{CH_3}_{CH_3}{>}CO+CaCO_3.$$

Acetone.



$${}^{CH_3.COO}_{CH_3.COO}{>}Ca+{}^{C_2H_5COO}_{C_2H_5COO}{>}Ca=2\,{}^{C_2H_5}_{CH_3}{>}CO+2CaCO_3.$$

Calcium Propionate. Ethyl Methyl Ketone.

On extending this reaction to the calcium salts of adipic, pimelic and suberic acids, cyclo-paraffin ketones are produced.

2A. ALDEHYDES OF THE SATURATED SERIES, PARAFFIN ALDEHYDES, $C_nH_{2n+1}.CHO$

The aldehydes exhibit in their properties a gradation in behaviour similar to that of the alcohols. The lower members are volatile liquids, soluble in water, and have a peculiar odour, but the higher are solids, insoluble in water, and cannot be distilled without decomposition. In general they are more volatile and dissolve with more difficulty in water than the alcohols. Chemically the aldehydes are neutral substances (B. **39**, 344).

The reactivity of the aldehydes places them amongst the most important substances for purposes of synthesis, and it is for this reason that the large number of methods for their preparation is being considerably increased, especially during the latter years (Bull. Soc. Chim. [3] **31**, 1306).

Formation.—(1) By the oxidation of primary alcohols, whereby the —$CH_2.OH$ group becomes changed to —CHO (p. 190).

The above oxidation may be effected by atmospheric oxygen in presence of spongy platinum, and by the action of potassium dichromate or MnO_2 and dilute sulphuric acid (B. **5**, 699). Chlorine acts similarly in that it first oxidizes the primary alcohols, but then substitutes the alkyl groups of the aldehydes which have been formed (p. 196).

Oxidation of alcohol leads to a good yield of aldehyde with the lower members of the series only, where the product is sufficiently volatile to escape quickly from the region of reaction; otherwise the aldehyde is further oxidized to a carboxylic acid, which in turn unites with some of the unchanged alcohol to form an ester.

(2) A direct decomposition of a primary alcohol into H_2 and an aldehyde is brought about by passing alcohol vapours through a red hot tube, or, better, over finely divided copper at 200–350° (B. **36**, 1990; C. 1905, I. 1002).

(3) Primary amines are oxidized to aldehydes by the air in presence of powdered copper (comp. p. 163).

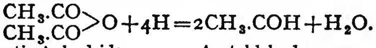
The following methods of preparation depend on the reduction of carboxylic acids:—

(4) By heating the calcium salts of fatty acids with calcium formate. This operation, when working with aldehydes which volatilize with difficulty, should be carried out under diminished pressure (p. 49) (B. **13**, 1413).

(5) By the action of nascent hydrogen (produced by sodium amalgam, or, better, by sodium on the moist ethereal solution B. **29**, R. 662) of the chlorides of the acid radicals or their oxides, the acid anhydrides:

$$CH_3.COCl+2H=CH_3.COH+HCl.$$

Acetyl Chloride. Acetaldehyde.



$$\begin{matrix}CH_3.CO\\CH_3.CO\end{matrix}\!\!>O+4H=2CH_3.COH+H_2O.$$

Acetic Anhydride. Acetaldehyde.

Hydrazones of the aldehydes are obtained by reduction of imido-ethers of carboxylic acids by sodium amalgam in acid solution in the presence of hydrazines (B. 38, 1362).

In accordance with methods (3) and (4) the aldehydes may be viewed as *hydrides of the acid radicals*.

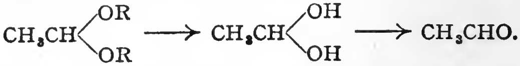
(6) Of practical importance is the preparation of aldehydes by the splitting up, or hydrolysis of their compounds:

(*a*) from aldehyde-ammonia and aldehyde-bisulphite compounds (see below); from oximes and hydrazones (p. 196);

(*b*) from aldehyde chlorides (p. 196) by heating them with water and lead oxide:

$$CH_3CHCl_2 \longrightarrow CH_3CH(OH)_2 \longrightarrow CH_3CHO;$$

(*c*) from ethers and esters of aldehyde hydrate, the *acetals* and *alkylidene diacetates*, by means of dilute alkalis or acids:



$$CH_3CH\left\langle\begin{matrix}OR\\OR\end{matrix}\right. \longrightarrow CH_3CH\left\langle\begin{matrix}OH\\OH\end{matrix}\right. \longrightarrow CH_3CHO.$$

In the course of these reactions 1,1-*glycols*, *dihydroxyl* compounds, should be formed; if they are, they instantly give up water and pass into aldehydes (p. 190). The following methods of formation from 1,2-glycols take their places systematically here.

(7) From ethylene glycol or its ethers, or from ethylene oxide by the withdrawal of water or alcohol and internal rearrangement:

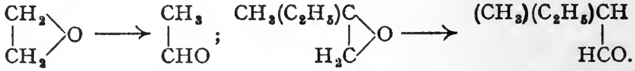
(*a*) Ethylene glycol, $CH_2OH.CH_2OH$, yields acetaldehyde when heated with zinc chloride, P_2O_5, sulphuric acid, etc., Diethylene ether, $O(CH_2.CH_2)_2O$, may be assumed to be an intermediate product (C. 1907, I. 15).

(*b*) Primary-secondary ethylene glycols yield a mixture of aldehydes and ketones when similarly treated.

(*c*) Primary-tertiary ethylene glycols yield aldehydes when heated with anhydrous formic and oxalic acid; the ethers, $R_2C(OH).CH_2OR$, react particularly easily (B. **39**, 2288; A. Ch. phys. [8] **9**, 484):

$$R_2C(OH).CH_2OC_2H_5 = R_2CH.CHO + C_2H_5OH.$$

(*d*) Ethylene oxide and its homologues, especially the primary-tertiary compounds, undergo internal rearrangement when heated with zinc chloride, a contact substance, or even alone, to form principally aldehydes (B. **36**, 2016; C. 1905, II. 237):



$$\begin{matrix}CH_2\\|\\CH_2\end{matrix}\!\!>O \longrightarrow \begin{matrix}CH_3\\|\\CHO\end{matrix};\quad \begin{matrix}CH_3(C_2H_5)C\\|\\H_2C\end{matrix}\!\!>O \longrightarrow \begin{matrix}(CH_3)(C_2H_5)CH\\|\\HCO.\end{matrix}$$

1,3-glycols also yield some aldehyde, together with trimethylene oxides.

(8) The sodium salts of the primary nitro-paraffins yield aldehydes and N_2O when treated with acids. Nitro-*αβ*- olefines of the formula $RCH{=}CHNO_2$ on reduction yield oximes of the aldehydes (C. 1903, II, 553):

$$(CH_3)_2C{:}CHNO_2 \xrightarrow{H} (CH_3)_2CH.CH{:}NOH \longrightarrow (CH_3)_2CH.CHO.$$

Compare the cleavage of *secondary chloramines*, R_2NCl, and *nitramines*, $R_2N.NO_2$ (pp. 167, 169), into aldehydes, also their formation from *αβ-olefine alkyl ethers*, $RCH : CHOC_2H_5$ (p. 129), by hydrolysis.

Since the nitro-olefines are formed from aldehydes by means of nitromethane (p. 151), these changes can be looked on as a step-by-step synthesis up the aldehyde series.

Such a building up of the aldehydes can be carried out by the organo-magnesium synthesis (p. 186).

(9) Alkyl magnesium halides with an excess of formic acid ester or formic acid dialkyl amides yield *aldehydes;* with orthoformic acid ester, *acetals* (p. 205); with isonitriles and with formimido-ethers, *aldehyde imides* (p. 211) (A. **347**, 348; B. **37**, 186, 875; C. 1904, I. 1077; 1905, I. 219):

$$RMgX + HCO_2C_2H_5 \longrightarrow RCHO + XMgOC_2H_5.$$
$$RMgX + HCON(C_2H_5)_2 \longrightarrow RCHO + XMgN(C_2H_5)_2.$$
$$RMgX + HC(OC_2H_5)_3 \longrightarrow RCH(OC_2H_5)_2 + XMgOC_2H_5.$$
$$RMgX + C_6H_5N{:}CHOC_2H_5 \longrightarrow RCH{:}NC_6H_5 + XMgOC_2H_5.$$

Also, formates are partially converted into aldehydes by means of alkyl magnesium halides (C. 1901, II. 765).

(10) $\alpha\beta$- olefine aldehydes, or better their acetals, yield paraffin aldehydes on reduction (B. **31**, 1900). Since the olefine aldehydes result from condensation of the lower paraffin aldehydes (p. 196) this also constitutes a method of passing synthetically up the aldehyde series.

Conversely, the following degradation reactions may be employed in the production of aldehydes.

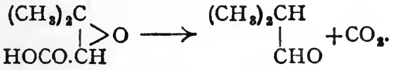
(11) α-Hydroxycarboxylic acids, RCH(OH)COOH, which are easily obtained from the fatty acids, yield aldehydes and some formic acid, or $CO+H_2O$, by treatment with sulphuric acid. A better method is to heat the hydroxy-acids, converting them by loss of water into *lactides*, and to distil these, so that they lose CO and pass into aldehydes (C. 1904, I. 1065):

$$\underset{\text{Lactic Acid.}}{CH_3CH(OH)COOH} = \underset{\text{Acetaldehyde}}{CH_3CHO} + \underset{\text{Formic Acid.}}{HCOOH.}$$

$$2C_4H_9CH(OH)COOH \longrightarrow C_4H_9CH{<}\begin{smallmatrix}O.CO\\CO.O\end{smallmatrix}{>}CHC_4H_9 \longrightarrow 2C_4H_9CHO+2CO.$$

α-Hydroxycapronic Acid. Valeraldehyde.

(12) Connected with this reaction is the formation of aldehyde by heating ethylene oxide carboxylic acid, or glycidic acids, whereby ethylene oxides are formed which become rearranged (Method of formation, 7d, p. 192) into aldehyde (C. 1906, II. 1297).



$$\begin{matrix}(CH_3)_2C\\ \;\;|{>}O\\ HOCO.CH\end{matrix} \longrightarrow \begin{matrix}(CH_3)_2CH\\ |\\ CHO\end{matrix} + CO_2.$$

Similarly, α-ketonic acids when heated with dilute sulphuric acid, yield aldehyde $+CO_2$.

$$CH_3COCOOH \longrightarrow CH_3CHO+CO_2.$$

(13) Olefines absorb ozone to form ozonides (p. 84), which may be decomposed by water, giving the results indicated as follows (A. **343**, 311):—

$$\underset{\text{Oleic Acid.}}{CH_3[CH_2]_7CH{:}CH[CH_2]_7COOH} \longrightarrow \underset{\text{Nonyl Aldehyde.}}{CH_3[CH_2]_7CHO} + \underset{\text{Azelaic Aldehydic Acid.}}{OCH[CH_2]_7COOH.}$$

This reaction is particularly important for the determination of constitution and for the preparation of dialdehydes and ketone-aldehydes.

Quite frequently aldehydes occur among the decomposition products of complex carbon compounds, such as albumins, as the result of their oxidation with manganese dioxide or dichromate and dilute sulphuric acid.

Nomenclature and Isomerism.—Empirically, the aldehydes are distinguished from the alcohols by possessing two atoms less of hydrogen —hence their name, suggested by *Liebig* (from *Alkohol dehydrogenatus*), *e.g.* ethyl aldehyde, propyl aldehyde, etc., etc. On account of their intimate relationship to the acids, their names are also derived from the latter, like acetaldehyde, propionaldehyde, etc.

In the " Geneva nomenclature " the names of the aldehydes are formed from the corresponding saturated hydrocarbons by the addition of the suffix *al*; thus ethyl- or acetaldehyde would be termed [ethanal] (p. 42).

As there is an aldehyde corresponding with every primary alcohol, the number of isomeric aldehydes of definite carbon content equals the number of possible primary alcohols having the same carbon content (p. 101). The aldehydes are isomeric with the ketones, the unsaturated olefine alcohols, and the anhydrides of the ethylene-glycol series, containing an equal number of carbon atoms, *e.g.*:

$CH_3.CH_2.CHO$ isomeric with $CH_3.CO.CH_3$ $CH_2{=}CHCH_2OH$ $CH_2{<}\substack{CH_2\\CH_2}{>}O$.

Propionaldehyde. Acetone. Allyl Alcohol. Trimethylene Oxide.

Reactions of the Aldehydes: A. *Reactions in which the carbon nucleus of the aldehydes remains the same.*

(1) Aldehydes, by oxidation, yield monocarboxylic acids with a like carbon content. *They are powerful reducing agents:*

$$CH_3C{\lessdot}\substack{H\\O}+O=CH_3{-}C{\lessdot}\substack{OH\\O}.$$

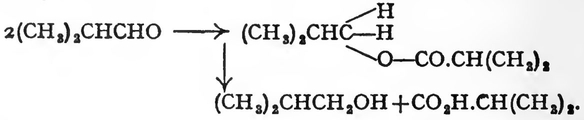
Their ready oxidation gives rise to important reactions serving for their detection and recognition. On adding an aqueous aldehyde solution to a weak ammoniacal silver nitrate solution, silver separates on the sides of the vessel as a brilliant mirror; alkaline copper solutions are also reduced. They impart an intense violet colour to a fuchsin solution previously decolorized by sulphurous acid. Further, aldehydes produce a violet-red coloration in a solution of diazobenzene sulphonic acid in sodium hydroxide, in the presence of sodium amalgam. On the exceptions to, and the limitation of, these reactions, see B. **14**, 675, 791, 1848; **15**, 1635, 1828; **16**, 657; **17**, R. 385.

When oxygen or air is conducted through the hot solution of an aldehyde (such as paraldehyde) in potassium hydroxide, a display of light is observed in the dark; many aldehyde derivatives, and even dextrose, behave similarly (B. **10**, 321). Aldehydes absorb oxygen from the air. The oxygen in this solution, like ozone, liberates iodine from a potassium iodide solution (B. **29**, 1454).

Aldehydes form addition-products with ozone, which, with water, yield aldehydes at low temperatures and acids at high (A. **343**, 326).

Salts of *nitrohydroxylaminic acid, e.g.* HON:NOONa, which is formed from hydroxylamine, alkyl nitrates, and sodium alcoholate, form hydroxamic acids with aldehydes, $RC{\lessdot}\substack{NOH\\OH}$, which are easily detected by the red colour given with ferric chloride (*a sensitive reaction for aldehydes*: C. 1904, I. 1204).

2. Acetaldehyde is resinified by alkalis; other aldehydes are transformed by alcoholic alkali solutions into acids and alcohols—particularly the aromatic aldehydes (see Benzaldehyde, Vol. II.), where the aldol condensation is impossible (p. 196). Among the aliphatic series, a similar reaction is brought about by barium hydroxide solution in the case of isobutyl aldehyde (C. 1901, II. 762). A carboxylic ester of an alcohol may be assumed to be formed as an intermediate product, which is decomposed by the barium hydroxide:



$$2(CH_3)_2CHCHO \longrightarrow (CH_3)_2CHC{\overset{\diagup H}{\underset{\diagdown O-CO.CH(CH_3)_2}{-H}}} \longrightarrow (CH_3)_2CHCH_2OH+CO_2H.CH(CH_3)_2.$$

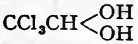
Esters do actually result, even from the simplest aldehydes, with anhydrous condensing agents, such as the aluminium alkylates; for instance, $Al(OCH_3)_3$ with formaldehyde, or trioxymethylenes, give methyl formate, with acetaldehyde ethyl acetate, with propionaldehyde propyl propionate, with chloral trichlorethyl trichloracetate, etc. (C. 1906, II. 1552).

The ease with which the double bond between the carbon-oxygen atoms is broken is the cause of a large number of addition reactions, which are in part followed by a loss of water.

(3) Aldehydes, by the addition of nascent hydrogen, or of molecular hydrogen in presence of reduced nickel (C. 1903, II. 708), are converted into the *primary alcohols*, from which they are obtained by oxidation:

$$CH_3.CHO+2H=CH_3.CH_2OH.$$

(4) *Behaviour of the aldehydes towards water and alcohols.* (*a*) Ordinarily, aldehydes do not combine with water (comp. p. 199; $CH_2(OH)_2$). The polyhalide aldehydes, *e.g. chloral, bromal, butyl chloral* (pp. 202, 203), however, have this power, and yield feeble and readily decomposable *hydrates*, representatives of dihydroxy alcohols or glycols, *both* hydroxyl groups of which are attached to the *same* carbon atom:

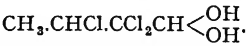


$$CCl_3CH<\begin{matrix}OH\\OH\end{matrix}$$

Chloral Hydrate.

$$CBr_3CH<\begin{matrix}OH\\OH\end{matrix}$$

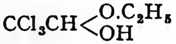
Bromal Hydrate.



$$CH_3.CHCl.CCl_2CH<\begin{matrix}OH\\OH\end{matrix}.$$

Butyl Chloral Hydrate.

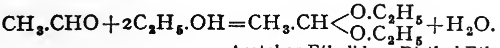
(*b*) It is also only the polyhalide aldehydes, *e.g. chloral*, which unite with alcohols, forming *aldehyde-alcoholates*:



$$CCl_3CH<\begin{matrix}O.C_2H_5\\OH\end{matrix}$$

Chloral Alcoholate.

(*c*) The ordinary aldehydes yield *acetals* with the alcohols at 100° (p. 205):

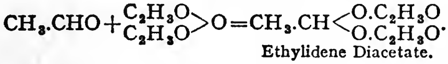


$$CH_3.CHO+2C_2H_5.OH=CH_3.CH<\begin{matrix}O.C_2H_5\\O.C_2H_5\end{matrix}+H_2O.$$

Acetal or Ethylidene Diethyl Ether.

(5) *Behaviour of the aldehydes with hydrogen sulphide and mercaptans:* (*a*) *hydrogen sulphide* and hydrochloric acid convert the aldehydes into *trithioaldehydes:* (*b*) with *mercaptans* the aldehydes enter into an acetal synthesis under the influence of hydrochloric acid (p. 209).

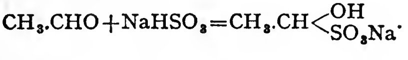
(6) Aldehydes and acid anhydrides unite to form esters of the hydroxy-alcohols or glycols, which are not stable in an isolated condition. Indeed, the aldehydes may be regarded as their anhydrides (p. 189):



$$CH_3.CHO+\begin{matrix}C_2H_3O\\C_2H_3O\end{matrix}>O=CH_3.CH<\begin{matrix}O.C_2H_3O\\O.C_2H_3O\end{matrix}.$$

Ethylidene Diacetate.

(7) Aldehydes unite in a similar manner with alkali bisulphites, forming crystalline compounds:



$$CH_3.CHO+NaHSO_3=CH_3.CH<\begin{matrix}OH\\SO_3Na\end{matrix}.$$

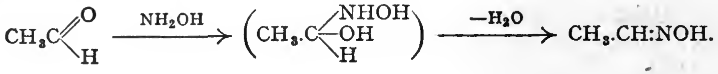
(Constitution, see p. 207.) The aldehydes may be liberated from these salts by distillation with dilute sulphuric acid or aqueous sodium hydroxide. This procedure permits of the separation and purification of aldehydes from other substances.

(8) *Behaviour of aldehydes with ammonia, primary alkylamines, hydroxylamine, and phenylhydrazine* ($C_6H_5.NH.NH_2$). (*a*) They unite directly with ammonia to form crystalline compounds, called *aldehyde-ammonias*. These are readily soluble in water but not in ether, hence ammonia gas will precipitate them in crystalline form from the ethereal solution of the aldehydes. They are rather unstable, and dilute acids again resolve them into their components. Pyridine bases are produced when the aldehyde-ammonias are heated.

(*b*) Aldehydes and primary amines combine, with loss of water, to form *aldehyde-imides* (p. 158).

(*c*) The aldehydes unite with *hydroxylamine* to form *aldoximes* with accompanying liberation of water (*V. Meyer*, B. **15**, 2778).

It is evident that at first, in these cases, there is formed an unstable intermediate product (compare chloral hydroxylamine, p. 212) corresponding with aldehyde-ammonia:



(*d*) The aldehydes behave similarly with *phenylhydrazine;* water separates and *hydrazones* (*E. Fischer*) result:

$$CH_3.CHO+H_2N.NHC_6H_5=CH_3.CH{:}NNHC_6H_5+H_2O.$$

These substances serve well for the detection and characterization of the aldehydes. The aldoximes and hydrazones, when boiled with acids, absorb water and revert to their parent substances. They yield primary amines when reduced (p. 158).

(*e*) Hydrazine, semicarbazide (*q.v.*), *p*-amido-dimethylaniline (B. **17**, 2939), amidophenols, and other aromatic bases (*Schiff*, B. **25**, 2020) react with aldehydes, similarly to phenylhydrazine and its substitution products.

(9) Compounds are formed by the action of phosphorus trichloride on aldehydes, which are converted by water into *hydroxalkyl phospho-acids, e.g.* $CH_3.CH(OH)PO(OH)_2$ (B. **18**, R. 111).

(10) Phosphorus pentachloride and phosphorus trichloro-dibromide cause the replacement of the aldehyde oxygen by chlorine or bromine and yield dichlorides and dibromides, in which the two halogen atoms are linked to a terminal carbon atom (p. 94):

$$CH_3CHO+PCl_5=CH_3CHCl_2+POCl_2.$$

(11) The hydrogen atoms of the alkyl groups of the aldehydes may be replaced by chlorine and bromine, as well as by iodine and iodic acid.

(12) The lower members of the homologous series of the aldehydes polymerize very readily. The *polymerization* of the aldehydes and thioaldehydes depends on the union of several aldehyde radicals, $CH_3.CH=$, through the oxygen or sulphur atoms (A. **203**, 44). This phenomenon will be fully treated under formaldehyde and acetaldehyde (p. 197).

B. *Nucleus synthetic Reactions of the Aldehydes.*

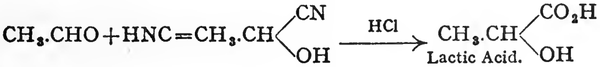
(1) *Aldol Condensations.*—Two or more aldehyde molecules may unite together, under proper conditions, by means of their carbon linkings. Thus, aldehyde alcohols are formed from two aldehyde molecules, *e.g.* acetaldehyde yields *Aldol* (*Würtz*) or β-hydroxybutyraldehyde, $CH_3.CHOH.CH_2.CHO$ (*q.v.*); from three aldehyde molecules fatty acid esters of the glycols are formed, as for example, isobutyl aldehyde which gives rise to *monoisobutyryl octyl glycol,* $(CH_3)_2.CH.CH(OH).C(CH_3)_2.CH_2OCO.CH(CH_3)_2$ (C. 1898, II. 416).

Similarly, aldehyde or chloral and acetone (p. 221), aldehyde and malonic or cyanacetic ester and others, unite with one another. But almost invariably the resulting hydroxy-derivatives split off water and pass into unsaturated bodies: aldol into *crotonaldehyde*, $CH_3CH{=}CH.CHO$, for example. On the other hand, if the aldehyde group is joined to a secondary alcohol radical, the aldol condensation occurs as before, but no olefine aldehyde can be obtained from the aldol formed. If the aldehyde group is united to a tertiary alcohol radical, no aldol condensation takes place (C. 1901, I. 1266).

These are nucleus-syntheses and are often termed **condensation reactions.** The reagents suitable for the production of such reactions are mineral acids, zinc chloride, alkali hydroxides, solutions of sodium acetate or potassium cyanide, small quantities of amines or their salts, etc. Condensation reactions, in which an aliphatic aldehyde plays the rôle of one of the component or parent substances, will be frequently encountered. A reaction discovered by *Perkin*, Sr., when working with aromatic aldehydes, has been employed quite frequently to unite aldehydes and acetic acid, as well as mono-alkyl acetic acids, in such a manner that the products are unsaturated monocarboxylic acids (see *nonylenic acid*). The aldehydes unite in like manner with succinic acid, forming γ-lactone carboxylic acids—the *paraconic acids* (*q.v.*).

(2) Aldehydes can also unite with zinc or magnesium alkyls, whereby the double union between carbon and oxygen is broken. The action of water on the addition product produces a secondary alcohol (p. 106). Olefine alcohols result by the use of allyl iodide and zinc or magnesium (p. 124).

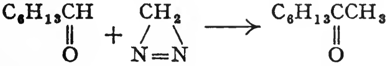
(3*a*) Aldehydes also combine with hydrogen cyanide, yielding *hydroxy-cyanides* or cyanhydrins—the *nitriles* of *a-hydroxy-acids* (*q.v.*), which will be discussed after the *a-hydroxy-acids* themselves, and which can be obtained from them by means of hydrochloric acid:



$$CH_3.CHO+HNC=CH_3.CH{<}\begin{matrix}CN\\OH\end{matrix}\xrightarrow{HCl}\underset{\text{Lactic Acid.}}{CH_3.CH}{<}\begin{matrix}CO_2H\\OH\end{matrix}$$

(*b*) Aldehydes and ammonium cyanide react together, when water separates, and the *nitriles of a-amino-acids, e.g.* $CH_3.CH{<}\begin{matrix}NH_2\\CN\end{matrix}$, result. When treated with hydrochloric acid they yield amino-acids (*q.v.*). The same *amino-nitriles* are produced by the action of CNH on the aldehyde-ammonias, and from the hydroxy-cyanides and ammonia. Cyanides of *a-anilino* and *a-phenylhydrazino-acids* are formed by the addition of hydrocyanic acid to the *aliphatic aldehyde-anilines* and *aldehyde phenylhydrazones* and *aldoximes* (B. **25**, 2020).

(4) Diazomethane (p. 213) and aldehydes produce alkyl-methyl ketones, with evolution of nitrogen, and probably with the formation of an intermediary addition product (B. **40**, 479, 847):



Aromatic diazo-compounds react similarly with many aldoximes, forming fatty-aromatic ketoximes (B. **40**, 737).

Formic Aldehyde, *Methyl Aldehyde* [Methanal], $H.C{<}\begin{matrix}O\\H\end{matrix}$, m.p. about $-92°$ (B. **34**, 635), b.p. about $-21°$, $D^{-}{}_{80}=0{\cdot}9172$, $D_{-20}=0{\cdot}8153$, was discovered by *A. W. Hofmann*, and was until recently only known in aqueous solution and in vapour form. It may, as was shown by *Kekulé*, be condensed, by lowering the temperature to a colourless liquid. Liquid formaldehyde changes slowly at $-20°$, rapidly at the ordinary temperature, with a crackling noise, into *trioxymethylene*, $(CH_2O)_3$ (B. **25**, 2435). This polymeric modification was known before the simple formaldehyde, into which it is changed by heat. Formaldehyde possesses a sharp, penetrating odour, and destroys bacteria of the most varied types; it is, therefore, applied (under the name of *formalin*) either in solution or as a gas, for disinfecting purposes. Many of its compounds with organic bodies are suitable for this purpose, as they regenerate formaldehyde more or less easily (B. **27**, R. 757, 803; **28**, R. 938; **29**, R. 178, 288, 426; C. 1900, I. 263, 791, etc.).

Methods of Formation.—(1) It is produced when the vapours of methyl alcohol, mixed with air, are conducted over an ignited platinum spiral or ignited copper gauze (J. pr. Ch. **33**, 321; B. **19**, 2133; **20**, 144; A. **243**, 335): lamps have been constructed for this purpose (B. **28**, 261).

(2) When chlorine and bromine act on methyl alcohol, formaldehyde is produced (B. **26**, 268), and is converted by them in sunlight into halogen acids and carbon dioxide (B. **29**, R. 88).

(3) If a mixture of methane (obtained from the distillation of wood, p. 71) and air is passed over heated copper gauze, formaldehyde is formed (C. 1905, I. 1132).

(4) It also arises in small quantity in the distillation of *calcium formate*. (5) Further, by the digestion of *methylal*, $CH_2(OCH_3)_2$ (p. 205), with sulphuric acid (B. **19**, 1841). (6) From the nitrile of acetyl glycollic acid, $CH_3.COOCH_2CN$, by the action of an ammoniacal silver solution (C. 1900, II. 312).

Technically, formaldehyde is prepared from methyl alcohol or methane, and its 40 per cent. aqueous solution and many derivatives are known to commerce; the year's production of formaldehyde reaches a million kg. (Z. angew. Ch. **19**, 1412). The strength of the solution can be estimated by converting the formaldehyde into *hexamethylene tetramine* $(CH_2)_6N_4$ (B. **16**, 1333; **22**, 1565, 1929; **26**, R. 415), or into dimethylene *p*-dihydrazinophenyl (B. **32**, 1961). The following methods are, however, more exact. The formaldehyde is transformed by hydrogen peroxide in alkaline solution of known strength into sodium formate and hydrogen, under the influence of its own heat generation:

$$2CH_2O+2NaOH+H_2O_2=2HCO_2Na+2H_2O+H_2.$$

From the back titration of the unused alkali the quantity of formic acid can be found.

Also, silver oxide or Cu_2O generate hydrogen from an alkaline formaldehyde solution (B. **36**, 3304). By the silent electric discharge, formaldehyde is partially decomposed into CO and H_2 (C. 1906, II. 227). H_2O_2 or BaO_2 in acid or neutral solution change formaldehyde into CO_2 and H_2 (B. 37, 515).

The estimation can also be carried out by treatment with an alkaline iodine solution and back titration with thiosulphate (C. 1905, I. 630).

Formaldehyde and sodium sulphite solution unite with liberation of sodium hydroxide, the titration of whch gives the quantity of formaldehyde. This reaction can also be employed for the estimation of aldehyde polymers (C. 1904, II. 263).

Dilute solutions of the alkali hydroxides partially transform formaldehyde into formic acid and methyl alcohol (comp. p. 194 and B. **38**, 2556). A modified aldol condensation occurs with excess of such alkalis as lime, calcium carbonate, or lead oxide (p. 196), giving rise to glycol aldehyde, $C_2H_4O_2$, *i*-arabinose, $C_5H_{10}O_5$, and various hexoses, $C_6H_{12}O_6$, of which the principal is α-acrose or $[d+l]$—fructose (B. **39**, 45, 1592).

This reaction gives a powerful support to the theories of assimilation of carbon dioxide in plants (B. **3**, 67; J. pr. Ch. [2] **33**, 344).

Formaldehyde, acted on by acetaldehyde and lime yields penta-erythritol, $C(CH_2OH)_4$ (B. **26**, R. 713); with nitromethane (p. 151) it gives nitro-tert.-butyl glycerol, $NO_2C.(CH_2OH)_3$; with picoline (Vol. II.) it yields trimethylolpicoline, $(C_5H_4N)C(CH_2OH)_3$. Thus, formaldehyde shows a strong tendency to unite repeatedly with reactive CH_3- groups, to form aldol-like bodies of increasing complexity.

In the very numerous reactions of formaldehyde its oxygen unites with two hydrogen atoms of the reacting body to yield water. It is immaterial whether the hydrogen is in union with carbon, nitrogen, or oxygen. The products are diphenylmethane derivatives, methylene aniline, and formals of polyhydric alcohols (A. **289,** 20).

Polymeric Modifications of Formaldehyde.—The concentrated aqueous solution of formic acid not only contains volatile CH_2O, but also the hydrate $CH_2{<}^{OH}_{OH}$, *i.e.* hypothetical methylene glycol, and non-volatile *polyhydrates, e.g.* $(CH_2)_2O(OH)_2$, corresponding with polyethylene glycols. Therefore the determinations of the molecular weight of the solution, by the method of Raoult, have yielded different values (B. **21,** 3503; **22,** 472). On complete evaporation of the solution the hydrates condense to the solid water-soluble *paraformaldehyde,* $(CH_2O)_n$, possibly *diformaldehyde,* $(CH_2O)_n$.

Trioxymethylene, $(CH_2O)_3$, *Metaformaldehyde* (*Butlerow*), m.p. 171–172°, is distinguished from the so-called paraformaldehyde, whose simplicity has not yet been established, by its insolubility in water, alcohol, and ether. It is obtained by the action of silver oxide on *methylene iodide,* or by heating *methylene diacetate* ester with water to 100°: by distilling *glycollic acid* with a little concentrated sulphuric acid, and by passing monochloracetic acid through a red-hot tube (C. 1898, I. 372). It is a white, indefinitely crystalline mass. The vapours have the formula CH_2O, which corresponds with their density. When cooled they again condense to the trimolecular form. When it is heated with water to 130° it changes to the simple molecule CH_2O, but by prolonged heating carbon dioxide and methyl alcohol are produced (B. **29,** R. 688).

When dry trioxymethylene is heated with a trace of sulphuric acid to 115° in a sealed tube it is changed into the isomeric *α-Trioxymethylene,* $(CH_2O)_3$, m.p. 60–61° (B. **17,** R. 567).

The polymeric modifications of formaldehyde have not yet been as successfully studied as the polymeric acetaldehydes (C. 1904, II. 21, 585).

In contact with peroxide, such as BaO_2 and SrO_2, and in the presence of water, the polymerized formaldehydes are catalytically changed into the simple form, accompanied by the disengagement of a considerable quantity of heat (C. 1906, II. 1135).

Acetaldehyde, *Ethyl Aldehyde, Ethylidene Oxide* [Ethanal], $C_2H_4O = CH_3.CHO$, m.p. −120°, b.p. 20·8°, $D_0=0{\cdot}8009$ (B. **23,** 638), is prepared according to the usual methods: (1) From ethyl alcohol; (2) from calcium acetate; (3) from acetyl chloride or acetic anhydride; (4) from ethylidene chloride from acetal and ethylidene diacetate; (5) from ethylene oxide; (6) from lactic acid; (7) from sodium nitroethane; and (8) from acetylene (p. 86). It occurs in the first runnings in the rectification of spirit, and is formed, too, by the oxidation of alcohol when filtered through wood charcoal (p. 115).

History.—In 1774 *Scheele* noticed that aldehyde was formed when alcohol was oxidized with manganese dioxide and sulphuric acid. *Döbereiner,* however, was the first to isolate the aldehyde in the form of aldehyde-ammonia, which he gave for investigation to *Liebig,* who then established the composition of aldehyde and showed its relation to alcohol. It was *Liebig* who introduced the name *Al*(cohol)-*dehyd*(*e*)(rogenatus) into chemical science (A. **14,** 133; **22,** 273; **25,** 17). Ordinary aldehyde readily polymerizes to liquid *paraldehyde,* and solid *metaldehyde. Fehling* first observed the former, and *Liebig* the latter. *Kekulé* and *Zincke* determined the conditions of formation for the aldehyde modifications and cleared up the somewhat confused reaction relations (A. **162,** 125).

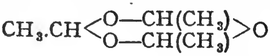
Preparation.—90 per cent. ethyl alcohol is oxidized by dropping into it a mixture of a solution of 3 parts of potassium dichromate in 12 parts of water and 4 parts of concentrated sulphuric acid (B. **27**, R. 471). The escaping aldehyde vapours are conducted into an ethereal solution of ammonia, when the aldehyde-ammonia separates in a crystalline form. Pure aldehyde may be liberated from this by dilute sulphuric acid, and dried over dehydrated calcium chloride.

Acetaldehyde is a mobile, peculiar-smelling liquid, miscible in all proportions with water, ether and alcohol. It is prepared technically in order to obtain *paraldehyde* and *quinaldine* (*q.v.*).

Polymeric Aldehydes.—Small quantities of acids (HCl, SO_2) or salts (especially $ZnCl_2$, CH_3CO_2Na) convert aldehyde at *ordinary temperatures* into **paraldehyde**, $(C_2H_4O)_3$, m.p. 124°, $D_{20}=0{\cdot}9943$; the change is accompanied by evolution of heat and contraction in volume and is particularly rapid, if a few drops of sulphuric acid be added to the aldehyde. Paraldehyde is a colourless liquid, and dissolves in about 12 vols. H_2O; it is, however, more soluble in the cold than when warm. This behaviour would point to the formation of a hydrate. The vapour density agrees with the formula $C_6H_{12}O_3$. Paraldehyde is employed in medicine as a soporific. When distilled with sulphuric acid ordinary aldehyde is generated. Bromine at 0° enters the molecule without disturbance, forming parabromacetaldehyde (C. 1900, I. 1201).

Metaldehyde, $(C_2H_4O)_3$ or $(C_2H_4O)_4$ (C. 1902, II. 1096), is produced by the same reagents (see above) acting on ordinary aldehyde *at temperatures below* 0°. It is a white crystalline body, insoluble in water, but readily dissolved by hot alcohol and ether. If heated to 112°–115° it sublimes without previously melting, and passes into ordinary aldehyde with only slight decomposition. When heated in a sealed tube the change is complete. Exposed for several days to a temperature varying from 60° to 65°, metaldehyde passes into aldehyde and paraldehyde (B. **26**, R. 775).

Chemical behaviour, refractive power, and specific volume point to a single linkage of oxygen and carbon; therefore the three oxygen atoms unite the three ethylidene groups to a ring of six members:

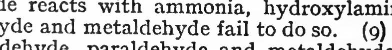


$$\mathrm{CH_3.CH}<\begin{matrix}\mathrm{O{-}CH(CH_3)}\\ \mathrm{O{-}CH(CH_3)}\end{matrix}>\mathrm{O}$$

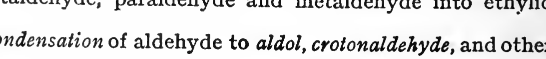
(B. **24**, 650; **25**, 3316; **26**, R. 185).

They may be considered cyclic ethers of *ethylidene glycol*, of which the anhydride is acetaldehyde.

Behaviour of Acetaldehyde (*Paraldehyde* and *Metaldehyde*). (1) In the air acetaldehyde slowly oxidizes to acetic acid. It produces a silver mirror from an ammoniacal silver nitrate solution. Paraldehyde and metaldehyde do not reduce silver solutions. (2) Alkalis convert acetaldehyde into *aldehyde resin*. (3) It is changed to *ethyl alcohol* by nascent hydrogen. (4) Aldehyde unites with alcohol to form *acetal* (p. 205). (5) Hydrogen sulphide converts it into *thioaldehyde* (p. 208), and with *mercaptans* it forms *mercaptals* (p. 209). (6) Acetic anhydride changes it to *ethylidene diacetate* (p. 207). (7) On shaking aldehyde with a very concentrated solution of an alkali bisulphite crystalline compounds separate, $CH_3.CH(OH)SO_3K$, which are resolved into their components when treated with acids (p. 207):



$$\mathrm{CH_3.CHO+HKSO_3=CH_3.CH}<\begin{matrix}\mathrm{SO_3K}\\ \mathrm{OH}\end{matrix}$$



$$\mathrm{CH_3.CH}<\begin{matrix}\mathrm{SO_3K}\\ \mathrm{OH}\end{matrix}\mathrm{+HCl=CH_3.CHO+SO_2+H_2O+KCl.}$$

Paraldehyde and metaldehyde do not unite with the bisulphites of the alkalis. (8) Acetaldehyde reacts with ammonia, hydroxylamine, and phenylhydrazine, whilst paraldehyde and metaldehyde fail to do so. (9) Phosphorus pentachloride converts acetaldehyde, paraldehyde and metaldehyde into ethylidene chloride (p. 207).

For the *condensation* of aldehyde to *aldol*, *crotonaldehyde*, and other compounds, see p. 196.

Aldehyde combines with hydrocyanic acid, the product being the nitrile of the lactic acid of fermentation, which may be synethesized in this manner.

The **homologues of formic and acetaldehydes** are prepared either (1) by the oxidation of the corresponding primary alcohols; or (2) by the distillation of the calcium or barium salts of the corresponding fatty acids, mixed with calcium or barium formate; (3) by transformation of ethylene oxide or glycol ethers; (4) by organo-magnesium synthesis; and (5) from the next higher α-hydroxy-fatty acid (C. 1904, II. 509).

Name.	Formula.	M.P.	B.P.
Propyl Aldehyde [Propanal] . . .	$CH_3CH_2.CHO$	—	49°
n-Butyl Aldehyde [Butanal] . . .	$(CH_3)(CH_2)_2.CHO$	—	75°
Isobutyl Aldehyde [Methyl Propanal] .	$(CH_3)_2CH.CHO$	—	61°
n-Valeraldehyde [Pentanal]	$(CH_3)[CH_2]_3CHO$	—	103°
Isovaleraldehyde [2-Methylbutanal (4)]	C_4H_9CHO	—	92°
Methyl Ethyl Acetaldehyde . . .	C_4H_9CHO	—	91°
Trimethyl Acetaldehyde (B. 24, R. 898)	$(CH_3)_3C.CHO$	—	74°
n-Capric Aldehyde	$CH_3.[CH_2]_4CHO$	—	128°
Methyl n-Propyl Acetaldehyde . . .	$C_5H_{11}CHO$	—	116°
Isobutyl Acetaldehyde	$C_5H_{11}CHO$	—	121°
Œnanthyl Aldehyde, *Œnanthol* . . .	$CH_3[CH_2]_5CHO$	—	155°
[Octanal], $C_8H_{16}O$	$CH_3[CH_2]_6.CHO$	—	81° (32 mm.)
Capric Aldehyde, $C_{10}H_{20}O$ . . .	$CH_3[CH_2]_8CHO$	—	106° (15 mm.)
[Undecanal], $C_{11}H_{22}O$ . . .	$CH_3[CH_2]_9.CHO$	−4°	117° (18 mm.)
Lauric Aldehyde, $C_{12}H_{24}O$ . . .	$CH_3[CH_2]_{10}CHO$	44·5°	142° (22 mm.)
[Tridecanal], $C_{13}H_{26}O$ . . .	$CH_3[CH_2]_{11}.CHO$	—	152° (24 mm.)
Myristic Aldehyde, $C_{14}H_{28}O$ . . .	$CH_3[CH_2]_{12}CHO$	52·5°	168° (22 mm.)
[Pentadecanal], $C_{15}H_{30}O$ . . .	$CH_3[CH_2]_{13}.CHO$	—	185° (25 mm.)
Palmitic Aldehyde, $C_{16}H_{82}O$ . . .	$CH_3[CH_2]_{14}CHO$	58·5°	192° (22 mm.)
Margaric Aldehyde, $C_{17}H_{34}O$ . . .	$CH_3[CH_2]_{15}CHO$	36°	204° (26 mm.)
Stearic Aldehyde, $C_{18}H_{36}O$ . . .	$CH_3[CH_2]_{16}CHO$	63·5°	212° (22 mm.)

Propyl aldehyde, by the action of hydrochloric acid, yields both *parapropyl aldehyde,* b.p. 169°, and *metapropyl aldehyde,* m.p. 180°. They have the molecular formula $(C_3H_6O)_3$ (B. **28**, R. 469).

Œnanthylic Aldehyde, *Œnanthol* (*οἶνος,* wine), is very readily prepared. It is formed together with undecylenic acid when castor oil is distilled under diminished pressure:

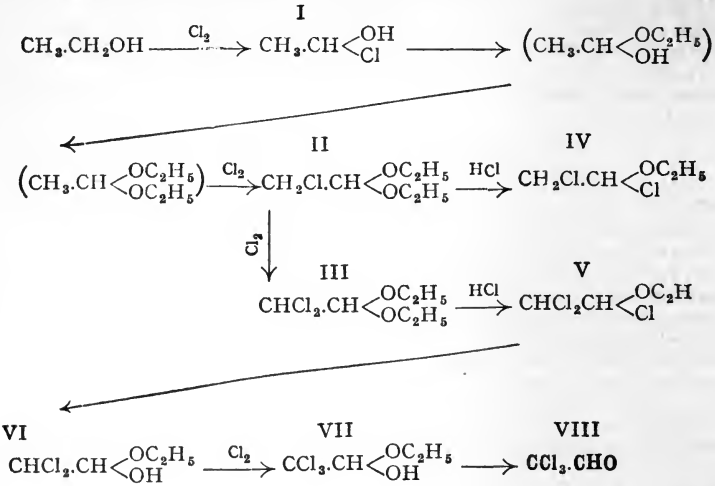
$$\underset{\text{Ricinoleic Acid.}}{C_{18}H_{34}O_3} = \underset{\text{Undecylenic Acid.}}{C_{10}H_{19}.CO_2H} + \underset{\text{Œnanthol.}}{CH_3.[CH_2]_5CHO}.$$

1. HALOGEN SUBSTITUTION PRODUCTS OF THE SATURATED ALDEHYDES

The most important member of this class of substances is **Trichloracetaldehyde,** *Chloral,* $CCl_3.CHO$, b.p. 97°, $D_0 = 1·541$, was discovered in 1832 by *Liebig* while engaged in studying the action of chlorine on alcohol (A. **1,** 182).

Fritsch considers that chlorine acts on alcohol to produce at first monochloralcohol or aldehyde chlorhydrin (I.). Alcohol and hydrochloric acid convert this, through the aldehyde alcoholate, into acetal. Neither substance can be isolated. Obviously acetal is chlorinated too easily to mono- and dichloracetal (II. and III.). These two compounds, under the influence of hydrochloric acid, pass into dichlor- and trichlor-ether (IV. and V.). Water changes the latter to dichloracetaldehyde alcoholate (VI.), which is converted by chlorine into chloral alcoholate. Sulphuric acid decomposes the latter into alcohol and chloral (VIII.)

(A. **279**, 288; C. 1897, I. 635, 801; compare also the chlorination of isobutyl alcohol, B. **27**, R. 507).



$$CH_3.CH_2OH \xrightarrow{Cl_2} \overset{\text{I}}{CH_3.CH<^{OH}_{Cl}} \longrightarrow \left(CH_3.CH<^{OC_2H_5}_{OH}\right) \longrightarrow$$

$$\left(CH_3.CH<^{OC_2H_5}_{OC_2H_5}\right) \xrightarrow{Cl_2} \overset{\text{II}}{CH_2Cl.CH<^{OC_2H_5}_{OC_2H_5}} \xrightarrow{HCl} \overset{\text{IV}}{CH_2Cl.CH<^{OC_2H_5}_{Cl}}$$

$$\downarrow Cl_2$$

$$\overset{\text{III}}{CHCl_2.CH<^{OC_2H_5}_{OC_2H_5}} \xrightarrow{HCl} \overset{\text{V}}{CHCl_2CH<^{OC_2H}_{Cl}} \longrightarrow$$

$$\overset{\text{VI}}{CHCl_2.CH<^{OC_2H_5}_{OH}} \xrightarrow{Cl_2} \overset{\text{VII}}{CCl_3.CH<^{OC_2H_5}_{OH}} \longrightarrow \overset{\text{VIII}}{\mathbf{CCl_3.CHO}}$$

Chloral hydrate, dichloracetic ester, trichlor-ethyl alcohol (B. **26**, 2756), and *ethylene monochlorhydrin* are by-products in the manufacture of chloral. (Private communication from *Anschütz* and *Stiepel*.)

Chloral is an oily, pungent-smelling liquid. When kept for some time it passes into a solid polymer.

Chloral shows greater tendency than acetaldehyde to sever its double linkage, between carbon and oxygen, and to enter into addition-reactions. Like acetaldehyde it not only combines with acetic anhydride, the alkali bisulphites, ammonia and hydrocyanic acid, but also with water, alcohol, hydroxylamine, formamide—four substances with which acetaldehyde is incapable of uniting.

The following reactions of chloral should also be observed: (1) The alkalis break it down into *chloroform* and alkali formates; (2) fuming sulphuric acid condenses it to *chloralide* (*q.v.*), trichlorolactic trichlorethylidene ether ester; (3) potassium cyanide changes it to dichloracetic ethyl ester (*q.v.*):

$$(1)\ CCl_3CHO + KOH = HC.Cl_3 + H.CO_2K.$$

$$(2)\ 3CCl_3.CHO \xrightarrow{(SO_3+H_2SO_4)} HCCl_3 + \underset{\text{Chloralide.}}{\begin{matrix}COO\\ \vdots \\ CCl_3CHO\end{matrix}>CH.CCl_3}.$$

Chloral Hydrate, *Trichlorethylidene Glycol*, $CCl_3.CH<^{OH}_{OH}$, m.p. 57°, b.p. 96–98°, results from the union of chloral with water. It is technically prepared on a large scale. It consists of large monoclinic prisms. The vapours dissociate into chloral and water. Chloral hydrate dissolves readily in water, possesses a peculiar odour and a sharp, biting taste; when taken internally it produces sleep, a fact which was discovered in 1869 by *Liebreich* (B. **2**, 269). It occurs in urine as *urochloralic acid* (*q.v.*). Concentrated sulphuric acid resolves the hydrate into water and chloral. It reduces ammoniacal silver solutions and when oxidized with nitric acid yields *trichloracetic acid*.

In chloral hydrate is found the first example of a body which, contrary to the rule, contains two hydroxyl groups attached to the same carbon atom, without the occurrence of the immediate spontaneous cleavage of water.

Other Halogen Substitution Products of Acetaldehyde.—Dichloracetaldehyde, b.p. 88–90°, results from the action of concentrated H_2SO_4, or better, benzoic anhydride (B. **40**, 217), on *dichloracetal,* $CHCl_2.CH(OC_2H_5)_2$. *Dichloracetaldehyde Hydrate,* $CHCl_2.CH(OH)_2$, m.p. 57° and b.p. 120°. *Monochloracetaldehyde,* b.p. 85°, is formed when *monochloracetal* (p. 205) is distilled with anhydrous oxalic acid. It polymerizes very readily (B. **15,** 2245).

Tribromaldehyde, Bromal, $CBr_3.CHO$, b.p. 172–173°, is perfectly analogous to chloral. Heated with alkalis, bromal breaks up into bromoform, $CHBr_3$, and a formate.

Bromal Hydrate, *Tribromethylidene Glycol,* $CBr_3CH(OH)_2$, m.p. 53°.

Bromal Alcoholate, $CBr_3CH(OH)(O.C_2H_5)$, m.p. 44°.

Dibromacetaldehyde Hydrate, $CHBr_2CH(OH)_2$, m.p. 59°, is prepared by the addition of HBrO to acetylene (C. 1900, II. 29).

Dibromacetaldehyde, b.p. 142°, is obtained by the bromination of paraldehyde.

Bromacetaldehyde, b.p. 80–105°, is produced, like monochloracetaldehyde, from *monobromacetal.*

Mono-iodoacetaldehyde, $CH_2I.CHO$, is made by acting on aldehyde with iodine and iodic acid. It is an oily liquid, which decomposes at 80° (B. **22,** R. 561).

The relations of the three chlor- (or brom-) acetaldehydes to the oxygen derivatives, of which they may be considered the chlorides, are shown in the following arrangement (p. 196):

$CH_2Cl.CHO$, Chloracetaldehyde.	$CH_2(OH).CHO$, Glycolyl Aldehyde.
$CHCl_2.CHO$, Dichloracetaldehyde.	$CHO.CHO$, Glyoxal.
$CCl_3.CHO$, Trichloracetaldehyde.	$CO_2H.CHO$, Glyoxylic Acid.

Higher Chlorine Substitution Products of the Aldehydes:

β-Chloropropionic Aldehyde, $CH_2Cl.CH_2.CHO$, m.p. 35°, from *acrolein,* $CH_2{=}CH.CHO$, and hydrochloric acid.

β-Chlorobutyraldehyde, $CH_3.CHCl.CH_2.CHO$, m.p. 96°, is produced from crotonaldehyde, $CH_3.CH:CH.CHO$, by the addition of HCl.

ααβ-Trichlorobutyraldehyde, Butyl Chloral, $CH_3.CHCl.CCl_2.CHO$, b.p. 163–165° (comp. acetamide).

Butyl Chloral Hydrate, $CH_3CHCl.CCl_2.CH(OH)_2$, m.p. 78°, is formed from α-chlorocrotonaldehyde and Cl_2. Alkalis decompose it into *formic acid,* potassium chloride, and *dichloropropylene,* $CH_3.CCl:CHCl$. When taken into the system it appears in the urine as *urobutyl chloralic acid* (*q.v.*), and is converted, by nitric acid, into trichlorobutyric acid.

The relations of these three chlorinated aldehydes to the unsaturated aldehydes, from which they are formed by the addition of HCl or Cl_2, and to the acids which they yield on oxidation, are shown in the following table:—

$$\begin{array}{ccccc}
\underset{\text{Acrolein.}}{CH_2{=}CH.CHO} & \xrightarrow{HCl} & \underset{\beta\text{-Chloropropionaldehyde.}}{CH_2Cl.CH_2.CHO} & \xrightarrow{HNO_3} & \underset{\beta\text{-Chloropropionic Acid.}}{\overset{\beta}{C}H_2Cl.\overset{\alpha}{C}H_2.CO_2H.} \\
\underset{\text{Crotonaldehyde.}}{CH_3.CH{=}CH.CHO} & \xrightarrow{HCl} & \underset{\beta\text{-Chlorobutylaldehyde.}}{CH_3.CHCl.CH_2CHO} & \longrightarrow & \underset{\beta\text{-Chlorobutyric Acid.}}{CH_3.CHCl.CH_2.CO_2H.} \\
\underset{\alpha\text{-Chlorocrotonaldehyde.}}{CH_3.CH{=}CCl.CHO} & \xrightarrow{Cl_2} & \underset{\text{Butylchloral.}}{CH_3.CHCl.CCl_2.CHO} & \longrightarrow & \underset{\text{Trichlorobutyric Acid.}}{CH_3.CHCl.CCl_2.CO_2H.}
\end{array}$$

Tetrabromobutyric Aldehyde, $CH_2Br.CHBr.CBr_2CHO$, m.p. 64°, b.p.$_{18}$ 146°, is prepared from paraldehyde and excess of bromine, with the intermediary production of crotonaldehyde. It does not form a hydrate, and is decomposed by alkalis into formic acid, bromopropargyl bromide, $H_2CBrC{\vdots}CBr$, and other bodies (C. 1905, II. 392; 1907, I. 1180).

PEROXIDES OF THE ALDEHYDES

Formaldehyde peroxide: *Diformal Peroxide Hydrate,* $HOCH_2O.OCH_2OH$, m.p. 51°, occurs during the slow combustion of ethyl ether (B. **18,** 3343). Ammonia changes it into *Hexaoxymethylene Diamine, Hexamethylene Triperoxydiamine,* $N(CH_2O.OCH_2)_3N$, which can also be easily prepared by the action of a solution of formaldehyde on ammonium sulphate dissolved in 3 per cent. hydrogen peroxide. The dry substance explodes as violently as diazobenzene nitrate on being heated, by friction or by a blow (B. **33,** 2486).

Acetaldehyde Peroxide has not, as yet, been closely investigated.

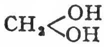
Dichloral Peroxide Hydrate, $CCl_3CH{<}\begin{smallmatrix}O\text{——}O\\ OH\ \ HO\end{smallmatrix}{>}CH.CCl_3$, m.p. 122°, is prepared from chloral and H_2O_2 in an ether solution or potassium persulphate in sulphuric acid (B. **33,** 2481).

On the *Ozonides* of the aldehydes, comp. also A. **343,** 326.

2. ETHERS AND ESTERS OF METHYLENE AND ETHYLIDENE GLYCOLS

In the introduction to the aldehydes (p. 189) it was explained that these bodies could be regarded as *anhydrides* of *glycols,* only capable of existing in exceptional cases. In the latter the two hydroxyl groups were linked to the same terminal carbon atom. Stable ethers and esters of these hypothetical glycols are, however, known.

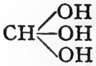
These hypothetical glycols might also be designated orthoaldehydes, because they bear the same relation to the aldehydes that the hypothetical orthocarboxylic acids sustain to the carboxylic acids:


$CH_2{<}\begin{smallmatrix}OH\\OH\end{smallmatrix}$

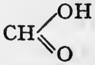
Orthoformaldehyde.

CH_2O

Formaldehyde.

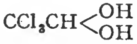

$CH{\equiv}(OH)_3$

Orthoformic Acid.

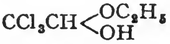

$CH{\begin{smallmatrix}OH\\ \| O\end{smallmatrix}}$

Formic Acid.

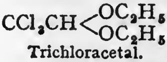
Basic and neutral mono- and dialkyl-ethers may be obtained from a dihydroxy-alcohol. The only mono-ether to be noticed in this connection is *chloral alcoholate,* which is mentioned under chloral hydrate:


$CCl_3CH{<}\begin{smallmatrix}OH\\OH\end{smallmatrix}$

Chloral Hydrate.

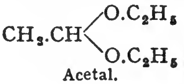

$CCl_3CH{<}\begin{smallmatrix}OC_2H_5\\OH\end{smallmatrix}$

Chloral Alcoholate.

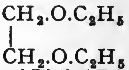

$CCl_3CH{<}\begin{smallmatrix}OC_2H_5\\OC_2H_5\end{smallmatrix}$.

Trichloracetal.

Alcohols not highly substituted by halogens are as little able to combine with a molecule of alcohol as with water. The dialkyl ethers are named *acetals,* from their best-known representative. They are isomeric with the ethers of the corresponding *true glycols,* whose OH-groups are attached to different carbon atoms:


$CH_3.CH{<}\begin{smallmatrix}O.C_2H_5\\O.C_2H_5\end{smallmatrix}$

Acetal.


$\begin{matrix}CH_2.O.C_2H_5\\ |\\ CH_2.O.C_2H_5\end{matrix}$

Glycol Diethyl Ether.

A. **Alcoholates or Carbinolates** of this type can only exist as addition products of alcohol with halogen substitution products of the aldehydes. In this they resemble the ethylidene glycols or aldehyde hydrates which are only stable when a sufficient number of hydrogen atoms have been replaced by halogens.

Chloral Alcoholate, $CCl_3CH{<}\begin{smallmatrix}CH\\OC_2H_5\end{smallmatrix}$, m.p. 65°, b.p. 114°, is the main product from the action of chlorine on alcohol (p. 201). It is also formed by treatment of chloral or chloral hydrate with alcohol. Water changes it slowly into chloral hydrate (B. **28,** R. 1013). *Chloral Dimethyl Ethyl Carbinolate,* $CCl_3CH(OH).OC(CH_3)_2C_2H_5$, is prepared from chloral and amylene hydrate (p. 121), or chlorine, amylene and hydrochloric acid (C. 1900, II. 1167).

B. **Acetals** are produced (1) when alcohols are oxidized with MnO_2 and H_2SO_4. The aldehyde formed at first unites with alcohol with the simultaneous separation of water:

$$3CH_3.CH_2OH \xrightarrow{O} CH_3CH(O.C_2H_5)_2 + 2H_2O.$$

(2) When aldehydes are heated with the alcohols alone to 100°; and from trioxymethylene and alcohols on the addition of ferric chloride (1–4 per cent.) (B. **27,** R. 506), or syrupy phosphoric acid (C. 1899, I. 910).

(3*a*) By the action of gaseous HCl on a mixture of alcohol and aldehyde, *chlorhydrin* (see Ethylene Glycol) being the first product:

$$CH_3CHO + C_2H_5OH \xrightarrow{HCl} CH_3CH{<}\begin{matrix}O.C_2H_5\\ Cl\end{matrix} \xrightarrow{C_2H_5OH} CH_3.CH{<}\begin{matrix}OC_2H_5\\ OC_2H_5\end{matrix} + HCl.$$

(3*b*) More suitably, by the action of 1 per cent. alcoholic hydrochloric acid on aldehyde (B. **31,** 545).

(4) By the action of metallic alcoholates on the corresponding chlorides, bromides and iodides.

(5) By the action of aldehydes on orthoformic ester or hydrochloric acid, formimido-ether and alcohol, *i.e.* on nascent orthoformic ester. This method is also employed for the preparation of acetal of the ketones (B. **31,** 1010; **40,** 3301).

On heating the acetals with alcohols, the higher alkyls are replaced by the lower (A. **225,** 265; C. 1901, I. 1146). When the acetals are digested with aqueous hydrogen chloride they are resolved into their constituents. They dissolve readily in alcohol and in ether, but with difficulty in water.

The acetals are considerably more stable towards alkalis than the aldehydes, and are mainly employed in those changes where aldehydes would be resinified or condensed.

Methylal, *Methylene Dimethyl Ether, Formal,* $CH_2(OCH_3)_2$, b.p. 42°, D.=0·855, is an excellent solvent for many carbon compounds. *Methylene Diethyl Ether, Diethyl Formal,* $CH_2(OC_2H_5)_2$, b.p. 89°. For the higher *methylals* see B. **20,** R. 553; **27,** R. 507. *Dichloromethylal,* $CH_2(OCH_2Cl)_2$, b.p. 166°, is obtained from the interaction of paraformaldehyde and dichloromethyl ether, $O(CH_2Cl)_2$; and also from a formaldehyde solution and HCl (A. **334,** 1). With sodium methoxide and ethoxide it yields respectively *Dimethoxymethylal,* b.p. 107°, and *Diethoxymethylal,* b.p. 140°, having the general formula $CH_2(OCH_2OR)_2$ (C. 1904, II. 416, 1906, II. 226).

Ethylidene Dimethyl Ether, Dimethyl Acetal, $CH_3CH(OCH_3)_2$, b.p. 64°.

Acetal, *Ethylidene Diethyl Ether,* $CH_3CH(OC_2H_5)_2$, b.p. 104°, D_{20}=0·8314, is produced in the process of brandy distillation. It is quite stable towards the alkalis, whilst dilute acids readily break it down into aldehyde and alcohol (B. **16,** 512).

Chlorine acting on acetal produces—

Monochloracetal, $CH_2Cl.CH(O.C_2H_5)_2$, b.p. 157° (B. **24,** 161), results from *Dichlorether,* $CH_2Cl.CHCl.OC_2H_5$, and alcohol or sodium ethoxide (B. **21,** 617); also from paraldehyde chlorine, and alcohol (for references, see *Monobromacetal,* below).

Dichloracetal, $CHCl_2.CH(O.C_2H_5)_2$, b.p. 183–184°.

Trichloracetal, $CCl_3.CH(OC_2H_5)_2$, b.p. 197°, is prepared from alcohol and chlorine.

Monobromacetal, $CH_2BrCH(OC_2H_5)_2$, b.p. 170°, is produced from acetal, bromine, and $CaCO_3$; or from paraldehyde, bromine, and alcohol (B. **25,** 2551; C. 1905, I. 1218; 1907, I. 1180). Sulphuric acid decomposes the chlorinated acetals into alcohol and *chlorinated aldehydes* (p. 196).

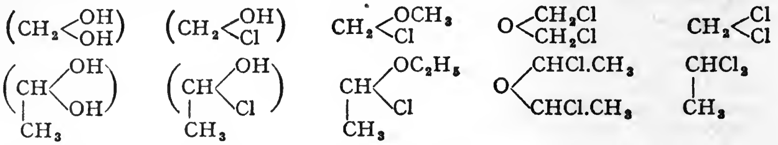
Iodoacetal, $I.CH_2.CH(OC_2H_5)_2$, b.p.$_{10}$ 100° (B. **30,** 1442). *Butyl Chloral-acetal,* $CH_3CHCl.CCl_2CH(OC_2H_5)_2$, b.p.$_{20}$ 123° (C. 1907, I. 152).

The polymeric modifications of aldehyde are closely related to the acetals, and result from an acetal-like union of similar molecules (p. 196). If molecules of different aldehydes take part in the reaction, there are obtained compounds similar to those formed by the polymeric aldehydes; chloral and formaldehyde, with concentrated H_2SO_4 give *Hexachlorodimethyl Tetroxan,* $CCl_3CH{<}\begin{matrix}O.CH_2.O\\ O.CH_2.O\end{matrix}{>}CHCCl_3$ and *Hexachlorodimethyl Trioxan,* $CCl_3CH{<}\begin{matrix}O.CH_2.O\\ O\end{matrix}{>}CHCl_3$ (B. **33,** 1432).

C. Dihalogen Aldehydes and Aldehyde Halohydrins their Alkyl Ethers and Anhydrides.

In describing the dihalogen substitution products of the paraffins it was indicated that compounds in which two halogen atoms occur joined to the same terminal carbon atom bear an intimate genetic relation to the aldehydes, and are therefore called aldehyde dihalides.

If these compounds be referred to glycols containing two hydroxyl groups attached to the same terminal carbon atom,—*i.e.* the hypothetical ortho-aldehydes,—then the aldehyde halides are the neutral haloid esters of these glycols. Between the ortho-aldehydes and the aldehyde halides stand the monohaloid esters, the aldehyde halohydrins, isomeric with the monohaloid esters of the true glycols,—the glycol halohydrins,—but only known in the form of their alkyl ethers, the *a*-monohaloids, ordinary ethers and their anyhdrides, the symmetrical *a*-disubstituted, ordinary ethers:



$$\left(CH_2<\begin{matrix}OH\\OH\end{matrix}\right) \quad \left(CH_2<\begin{matrix}OH\\Cl\end{matrix}\right) \quad CH_2<\begin{matrix}OCH_3\\Cl\end{matrix} \quad O<\begin{matrix}CH_2Cl\\CH_2Cl\end{matrix} \quad CH_2<\begin{matrix}Cl\\Cl\end{matrix}$$

$$\left(\begin{matrix}CH<\begin{matrix}OH\\OH\end{matrix}\\ |\\ CH_3\end{matrix}\right) \quad \left(\begin{matrix}CH<\begin{matrix}OH\\Cl\end{matrix}\\ |\\ CH_3\end{matrix}\right) \quad \begin{matrix}CH<\begin{matrix}OC_2H_5\\Cl\end{matrix}\\ |\\ CH_3\end{matrix} \quad O<\begin{matrix}CHCl.CH_3\\CHCl.CH_3\end{matrix} \quad \begin{matrix}CHCl_2\\ |\\ CH_3\end{matrix}$$

The genetic relations of the aldehyde halides to the aldehydes consist in the formation of aldehyde chlorides from the aldehydes by means of PCl_5, and the change undergone by the aldehyde chlorides when heated to 100° with water.

1. **Aldehyde Dihalides.**—The boiling points, melting points, and specific gravities of some of the simple aldehyde dihalides are given in the appended table. The inclosed numbers after the boiling points indicate diminished pressure:

Name.	Formula.	M.P.	B.P.	D.
Methylene Chloride	CH_2Cl_2	—	41°	1·37 (0°)
Methylene Bromide	CH_2Br_2	—	98°	2·54 (0°)
Methylene Iodide	CH_2I_2	+4°	181°	3·28 (15°)
Ethylidene Chloride	CH_3CHCl_2	—	60°	1·17 (20°)
Ethylidene Bromide	CH_3CHBr_2	—	110°	2·02 (20°)
Ethylidene Iodide	CH_3CHI_2	—	127° (171)	2·84 (0°)
Propylidene Chloride	$CH_3.CH_2CHCl_2$	—	86°	1·16 (14°)

Methylene Chloride is formed from CH_3Cl and Cl, by the reduction of chloroform by means of zinc in alcohol, and from trioxymethylene and PCl_5.

Methylene Bromide results on heating CH_3Br with bromine to 180°, and by the action of trioxymethylene on aluminium bromide, or phosphorus pentabromide.

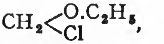
Methylene Iodide is produced when iodoform is reduced with HI, or better, with arsenious acid and sodium hydroxide (*Klinger*). It is characterized by a high specific gravity. Chlorine and bromine change it to methylene chloride and bromide (comp. ethylene, p. 80). Mercury changes it into ICH_2HgI (C. 1901, I. 1264).

Ethylidene Chloride, *Aldehyde Chloride,* is produced (1) from aldehyde by the action of PCl_5, (2) from vinyl bromide by means of hydrogen bromide, and (3) by treating copper acetylide with concentrated hydrochloric acid (A. **178**, 111) (comp. Ethylene, p. 80).

Ethylidene Bromide is obtained by the action of PCl_3Br_2 on aldehyde (B. 5, 289).

Ethylidene Iodide is obtained from acetylene and hydriodic acid (B. **28**, R. 1014).

2. **Alkyl Ethers of the Aldehyde Halohydrins, *a*-Monohaloid Ethers** result from the action of alcohols and haloid acids on the aldehydes. Alcohols or alcoholates readily convert them into acetals. *Monochloromethyl Ether,*



$CH_2<\begin{matrix}O.C_2H_5\\Cl\end{matrix}$, b.p. 60°; $D_{15}=1·1508$. *Monochloromethyl Propyl Ether,* $ClCH_2OC_3H_7$, b.p. 105–110°, and higher homologues are obtained from trioxymethylene hydrochloric acid and methyl, ethyl, propyl, etc., alcohol (A. **334**, 49; B. **36**, 1383). They are highly reactive bodies; with water they regenerate formaldehyde; with formates and acetates they yield *ether-esters* of the type $HCOOCH_2OR$; with magnesium alkyl halides they give simple *ethers* (p. 126); with magnesium in presence of ketones or carboxylic esters or magnesium-organic compounds such as $ROCH_2MgX$ (p. 186), they form *ethers of the ethylene glycols,*

$R''R'C(OH)CH_2OR$, or *diethers of the glycerols*, $R'C(OH)(CH_2OR)_2$; with mercury or copper cyanides they are converted into nitriles of alkoxyl glycollic acid $NC.CH_2OR$ (C. 1907, I. 400, 871). They yield hexamethylene tetramine with ammonia (p. 210), and form quaternary ammonium salts, $ClR_3NCH_2OCH_3$, with tertiary amines. *Monobromomethyl Ether*, b.p. 87°; $D._{12}=1·531$. *Monoiodomethyl Ether*, b.p. 124°; $D_{18}=2·0249$ (B. **26**, R. 933).

a-Monochlorethyl Ether, $CH_3CHCl.O.CH_2CH_3$, b.p. 98°, isomeric with ethylene chlorohydrin ethyl ether, $ClCH_2CH_2.O.C_2H_5$, is produced by the chlorination of ether, and by saturating a mixture of aldehyde and alcohol with hydrochloric acid, into which substances it is again resolved by water. *Monobromethyl Ether*, b.p. 105° (B. **18**, R. 322).

3. **Sym. aa'-Dihalogen Alkyl Ethers, Ethers of the Aldehyde Halohydrins.** The symmetrical dihalogen methyl ethers result from the action of the halogen acids on trioxymethylene (C. 1900, I. 1122; 1901, II. 26; A. **334**, 1). sym.-*Dichloromethyl Ether* $(CH_2Cl)_2O$, b.p. 105°, $D=1·315$, is also obtained, together with dichloromethylal from trioxymethylene and PCl_3. sym.-*Dibromomethyl Ether*, b.p. 150°. sym.-*Di-iodomethyl Ether*, b.p. 218°.

D. **Carboxylic Esters of Methylene and Ethylidene Glycols** are formed (1) from aldehydes and acid anhydrides; (2) from aldehydes and acid chlorides; (3) from the corresponding chlorides, bromides, and iodides by the action of silver salts. When boiled with water these esters break down into aldehydes and acids:

1. $CH_3CHO+(CH_3CO)_2O \quad =CH_3CH(OCOCH_3)_2.$

2. 

$$CH_3CHO+CH_3COCl \quad =CH_3CH\Big\langle{\substack{O.COCH_3\\ Cl}}.$$

3. $CH_2I_2+2CH_3CO_2Ag=CH_2(OCOCH_3)_2+2AgI.$

Methylene Diacetate, $CH_2(OCOCH_3)_2$, b.p. 170°. For higher homologues see C. 1902, II. 933; 1903, II. 656: *Ethylidene Diacetate*, $CH_3CH(O.COCH_3)_2$, b.p. 169°.

Chloral Diacetate, $CCl_3.CH(OCOCH_3)_2$, b.p. 221°. *Bromal Diacetate*, m.p. 76°.

Monochloromethyl Acetate and *Monobromomethyl Acetate*, $Br.CH_2OCOCH_3$, b.p. 130°, are prepared from trioxymethylene and acetyl chloride or bromide (C. 1901, II. 396). *Ethylidene Chlorhydrin Acetate, Monochlorethyl Acetate*, $CH_3CHCl.OCOCH_3$, b.p. 121·5°, is the parent substance for the preparation of *ether-esters* and *mixed ethers*. *Ethylidine Chlorhydrin Propionate*, b.p. 134–136°. Silver propionate with the first chlorhydrin forms the same *Aceto-ethylidine Propionate*, $CH_3COO.CH(CH_3)OCOC_2H_5$, b.p. 178·6°, as silver acetate with the second chlorhydrin. These facts argue for the equivalence of the carbon valencies (*Geuther*, A. **225**, 267).

Chloral Acetyl Chloride, $CCl_3CHCl(OCOCH_3)$, b.p. 193°.

Bromal Acetyl Chloride (C. 1900, II. 811).

Chloral Ethyl Acetate, $CCl_3.CH(OC_2H_5)OC_2O.CH_3$, b.p. 198° (C. 1901, I. 930).

E. **Aldehyde Bisulphites and Sulphoxylates.**

The aldehydes in aqueous solutions absorb sulphurous acid with the evolution of heat (B. **38**, 1076; C. 1904, II. 54, etc.). On evaporation the gas is driven off; but if bisulphite salts are added in the first place this does not occur, and crystallizable salts are obtained of the general formula $RCHOHSO_3Me$. The bisulphites serve to characterize the various aldehydes.

Previously these compounds were considered as being *a*-hydroxy-alkyl sulphonic acids. However, a comparison between hydroxy-methyl sulphonic acid (p. 210), obtained from the methyl alcohol, with formaldehyde shows at once that great differences exist. The first-named acid and its salts are very stable, and show little tendency to undergo transformation, whilst formaldehyde bisulphite and its higher homologues—

(1) are easily decomposed by hydrochloric acid or alkalis, regenerating the aldehyde;

(2) are easily transformed by aqueous solutions of alkali cyanides, forming aldehyde cyanhydrins or a-hydroxyacid nitriles (B. **37**, 4060; **38**, 213).

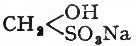
$$HO.CH_2.SO_3K+KNC=HOCH_2CN+K_2SO_3;$$

(3) are converted by ammonia or amines into alkylidene amino-sulphites (B. **37**, 4075; **38**, 1077):

$$HO.CH_2.SO_3Na+NH_3=NH_2.CH_2.SO_3Na+H_2O;$$

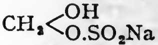
(4) yield derivatives of sulphoxylic acids by reduction (p. 208).

From these observations formaldehyde bisulphite and all similar bisulphite addition products of homologous aldehydes are looked upon as being the bisulphites of aldehyde ortho-hydrate, which are isomeric with the *a*-hydroxysulphonates (comp. p. 210, B. **38**, 1069):



$$\mathrm{CH_2}<\begin{matrix}\mathrm{OH}\\ \mathrm{SO_3Na}\end{matrix}$$

Sodium Hydroxymethyl Sulphonate.



$$\mathrm{CH_2}<\begin{matrix}\mathrm{OH}\\ \mathrm{O.SO_2Na}\end{matrix}$$

Formaldehyde Sodium Bisulphite.

Neutral sulphites also form aldehyde bisulphites with the liberation of alkali hydroxide, the titration of which serves as a method of quantitative estimation of the aldehyde (C. 1904, I. 1176, 1457):

$$\mathrm{RCHO+SO_3Na_2=RCHO.HSO_3Na+NaOH.}$$

Reduction of aldehyde bisulphites by zinc dust and acetic acid leads to the formation of aldehyde sulphoxylates (B. **38**, 1073; C. 1905, II. 1752, etc.).

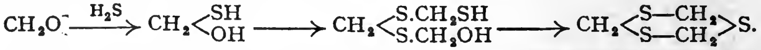
$$\mathrm{RCH(OH).OSO_2Na+2H=RCH(OH).OSONa+H_2O.}$$

Formaldehyde Sulphoxylate, $HOCH_2.OSONa+2H_2O$, withstands the action of alkalis better than formaldehyde bisulphite. It forms small rhombic prisms (C. 1905, I. 795). A finely crystallizing double compound of formaldehyde sulphoxylate and formaldehyde bisulphite (B. **38**, 2290) may be prepared from formaldehyde and sodium hydrosulphite, $Na_2S_2O_4$. This body, known under the name of *Rongalite*, is of technical importance in the dyeworks where, in discharge work, the reducing action of sodium hydrosulphite is developed at a raised temperature and then only acts on the azo-dyestuffs, indigo, etc., without attacking the fibre. Rongalite can be split up into its constituent compounds by fractional crystallization. Sulphoxylates react with amines similarly to the aldehyde bisulphites (p. 207).

3. SULPHUR DERIVATIVES OF THE SATURATED ALDEHYDES

In this class are (A) the *thioaldehydes*, their *polymeric modifications* and their *sulphones*; (B) the *mercaptals* or *thioacetals*, with their *sulphones*; and (C) the *hydroxysulphonic* and *disulphonic acids* of the aldehydes.

A. **Thioaldehydes, Polymeric Thioaldehydes and their Sulphones.**—The simple thioaldehydes are not well known, whilst the polymeric thioaldehydes are more accessible. All of them can be regarded as the alkyl derivatives of polymeric trithioformaldehyde, the trithiomethylene, discovered by *A. W. Hofmann*. They are formed when the aldehydes are acted on with H_2S and HCl. The H_2S adds itself to the C=O-group of the aldehydes, and *hydroxy-hydrosulphides* result, from which the trithioaldehydes arise:

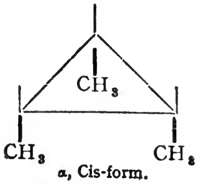


$$\mathrm{CH_2O}\xrightarrow{\mathrm{H_2S}}\mathrm{CH_2}<\begin{matrix}\mathrm{SH}\\ \mathrm{OH}\end{matrix}\longrightarrow\mathrm{CH_2}<\begin{matrix}\mathrm{S.CH_2SH}\\ \mathrm{S.CH_2OH}\end{matrix}\longrightarrow\mathrm{CH_2}<\begin{matrix}\mathrm{S{-}CH_2}\\ \mathrm{S{-}CH_2}\end{matrix}>\mathrm{S.}$$

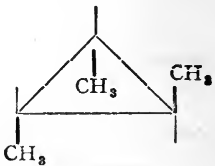
The trithioaldehydes are odourless solids, whereas the simple thioaldehydes and their mercaptan-like transposition products possess a persistent, disagreeable odour. Potassium permanganate oxidizes the trithioaldehydes first to *sulphide-sulphones* and then to *trisulphones*. The molecular weight of the trithioaldehydes has been determined both by vapour density and by the lowering of the freezing point of their naphthalene solution. *Klinger* first proposed the structure for the trithioaldehydes which corresponds with the formula of paraldehyde and was proved correct by the oxidation of the trithioaldehydes to trisulphones.

The isomeric phenomena of the trithioaldehydes were considered by *Baumann* and *Fromm* to be due to their space-configurations (B. **24**, 1426).

Proceeding from the same considerations, which served *Baeyer* in his explanation of the isomerism of the hexamethylene derivatives (see *Hexahydrophthalic Acids*), these chemists distinguished *a*-, *cis*- or maleïnoid and *β*, *trans*- or fumaroid modifications. *Camps* represents the spacial difference between the two trithioaldehydes in the following way:—



a, Cis-form.



β, Trans-form.

The C-atoms are assumed to be in the angles of the triangles, and the S-atoms are in the middle of the sides. The three alkyl groups are either upon the same side of the six-membered ring system: *α, cis*-form; or upon different sides of it: *β, trans*-modification. Only one disulphone-sulphide corresponds with the *cis*-modification, whilst *two* stereoisomeric disulphone-sulphides take the *trans*-form. On *Klinger's* interpretation of these phenomena as "*alloergatic isomerism,*" characterized by the various energy-contents of the isomers, compare fumaric and maleïc acids, see B. **32**, 2194.

Trithioformaldehyde, $[CH_2S]_3$, m.p. 216°, is prepared by boiling together formaldehyde, sodium thiosulphate, and hydrochloric acid. Probably an intermediate compound *formaldehyde thiosulphuric acid,* $CH_2(OH)S.SO_3H$, is formed, which breaks up on boiling into thioaldehyde and sulphuric acid (B. **40**, 865). On heating trithioformaldehyde with iodomethane and methyl alcohol, there is formed trimethyl sulphinium iodide (p. 145; C. 1906, I. 649). *α-Trithioacetaldehyde,* m.p. 101°, b.p. 246–247°, and *β-Trithioacetaldehyde,* $[CH_3CHS]_3$, m.p. 125–126°, b.p. 245–248°; at low temperatures the α-form predominates, but can be changed in considerable proportion into the β-form by the aid of catalysts such as iodine, zinc chloride, acetyl chloride, hydrochloric acid, etc. (B. **24**, 1457; C. 1905, II. 1720; compare also C. 1904, II. 21).

Sulphones of the Trithioaldehydes.—The trisulphones, resulting from the oxidation of the trithioaldehydes, are all to be considered as being alkylated derivatives of *trimethylene trisulphone.* The six methylene hydrogen atoms of trimethylene trisulphone are acidic like those of the methylenes in *malonic ester* (*q.v.*). They can be replaced by metals, and hexa-alkylated trimethylene sulphones can be synthetically prepared by the double decomposition of the alkali derivatives with alkyl iodides. These are identical with the oxidation products of the corresponding *trithioketones.* The primary product in the oxidation of a trithioaldehyde is a monosulphone, the secondary a disulphone, and finally a trisulphone is produced.

Trimethylene Trisulphone, $CH_2<\substack{SO_2—CH_2\\SO_2—CH_2}>SO_2$, and **Trimethylene Disulphone Sulphide,** $CH_2<\substack{SO_2.CH_2\\SO_2.CH_2}>S$, m.p. above 340°, as is also that of **Triethylidene Trisulphone,** $[CH_3CHSO_2]_3$ (B. **25**, 248).

The two isomeric trithioacetaldehydes yield **Triethylidene Disulphone Sulphide,** $CH_3.CH.<\substack{SO_2CH(CH_3)\\SO_2CH(CH_3)}>S$, m.p. 228–231°. "The isomerism of the trithioaldehydes vanishes in their oxidation products" (B. **26**, 2074; **27**, 1667).

Thialdine, $CH_3.CH<\substack{S.CH(CH_3)\\S.CH(CH_3)}>NH$, m.p. 43°, is produced by the action of NH_3 on α-trithioacetaldehyde (B. **19**, 1830), and of H_2S on aldehyde-ammonia (A. **61**, 2). It yields *ethylidene disulphonic acid* (p. 210) by oxidation. **Methyl Thialdine,** $(C_2H_4)_3S_2(NCH_3)$, m.p. 79° (B. **19**, 2378).

B. **Mercaptals or Thioacetals and their Sulphones.**

The *thioacetals,* corresponding with the *acetals* (p. 205), are called *mercaptals.* They are formed (1) from alkyl iodides and alkali mercaptides; (2) by the action of HCl on the aldehydes and mercaptans. First an addition product is formed such as $CH_2(OH)SC_5H_{11}$, which with a second mercaptan molecule loses water and yields a mercaptal. It is possible, therefore, to prepare mercaptals containing two different alkyl groups (B. **36**, 296). They are oils with very unpleasant odours, and are oxidized by $KMnO_4$ to sulphones.

$$CH_2<\begin{matrix}S.C_2H_5\\S.C_2H_5\end{matrix}\xrightarrow{\quad 4O \quad}CH_2<\begin{matrix}SO_2.C_2H_5\\SO_2.C_2H_5\end{matrix}.$$

Methylene Mercaptal, $CH_2(SC_2H_5)_2$, b.p. about 180°. *Ethylidene Mercaptal, Dithioacetal,* $CH_3CH(SC_2H_5)_2$, b.p. 186°. *Propylidene Mercaptal,* $CH_3CH_2CH(SC_2H_5)_2$, b.p. 198°.

In the sulphones of the mercaptals the methylene hydrogen (see above) is replaceable by akali metals. Mono- and dialkylated sulphones can be prepared from these akali derivatives. Again, the dialkylized sulphones may be obtained from the *mercaptols* (p. 226); *sulphonal* belongs to this class.

Methylene Diethyl Sulphone, $CH_2(SO_2C_2H_5)_2$, m.p. 104°, is readily soluble in water and in alcohol. It is formed in the oxidation of orthothioformic ethyl ester (*q.v.*). It condenses with formaldehyde, forming methylene dimethenyl tetraethyl sulphone (B. **33**, 1120). *Methylene Ethyl Phenyl Disulphone*, $CH_2(SO_2C_2H_5)(SO_2C_6H_5)$, m.p. 111° (B. **36**, 300). *Ethylidene Diethyl Sulphone*, $CH_3CH(SO_2C_2H_5)_2$, m.p. 75°, b.p. 320° with decomposition.

C. **Hydroxysulphonic Acids and Disulphonic Acids of the Aldehydes.**

Hydroxymethyl Sulphonic Acid, $CH_2(OH)SO_3H$, is formed together with *Hydroxymethylene Disulphonic Acid*, $CH(OH)(SO_3H)_2$, and *Methine Trisulphoni Acid*, $CH(SO_3H)_3$, by the action of fuming sulphuric acid on methyl alcohol and subsequent boiling of the product with water. Boiling acids or alkalis have no effect on it (comp. p. 208).

Methionic Acid, *Methylene Disulphonic Acid*, $CH_2(SO_3H)_2$, has long been known. It is produced when fuming sulphuric acid acts on *acetamide*, *acetonitrile*, *lactic acid*, etc. It is most conveniently made by saturating fuming sulphuric acid with acetylene (from calcium carbide), but *acetaldehyde disulphonic acid*, $CHO.CH(SO_3H)_2$ is the main product of reaction.

This acid can be completely decomposed by alkalis into formic and methionic acids:

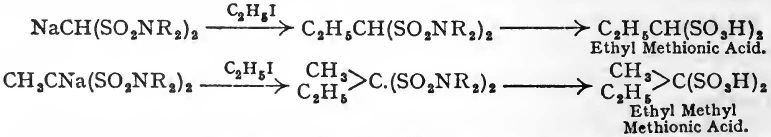
$$\underset{\text{Acetylene.}}{CH\vdots CH} \xrightarrow{O(SO_3H)_2} \underset{\substack{\text{Acetaldehyde}\\ \text{Disulphonic Acid.}}}{OCH.CH(SO_3H_2)} \xrightarrow{H_2O} \underset{\substack{\text{Formic}\\ \text{Acid.}}}{HO_2CH} + \underset{\substack{\text{Methionic}\\ \text{Acid.}}}{CH_2(SO_3H)_2}$$

Methionic acid crystallizes in deliquescent needles, which are not decomposed by boiling nitric acid. *Barium salt*, $CH_2(SO_3)_2Ba+2H_2O$, forms pearly leaflets dissolving with difficulty.

Methionic Methyl Ester, $CH_2(SO_3CH_3)_2$, m.p. 70°, b.p.$_{16}$ 194–200°: *ethyl ester*, m.p. 29°, results from the action of silver methionate on iodoalkyls, and is easily hydrolyzed by water. *Methionyl Chloride*, $CH_2(SO_2Cl)_2$, b.p.$_{10}$ 135°, $D_{15}=1{\cdot}82$, is formed from methionic acid and phosphorus pentachloride. It reacts energetically with water or alcohol, regenerating methionic acid. With amines, especially those of the aromatic series, it forms amides.

Methionic Anilide, $CH_2(SO_2NHC_6H_5)_2$, m.p. 193°, yields well-crystallizable or insoluble salts: $CH_2(SO_2NMeC_6H_5)_2$. *Methionic Diethylanilide*, $CH_2(SO_2H[C_2H_5]\text{-}C_6H_5)_2$, m.p. 113°

The esters, still better the dialkyl amides of methionic acid, react with potassium and sodium, evolving hydrogen and forming salts, $KCH(SO_3R)_2$ and $NaCH(SO_2NR_2)_2$ which readily undergo transformation with alkyl halides, acyl halides and carboxylic esters. As a result, *homologues of methionic acid* can be formed in the same way as malonic ester is caused to yield its homologues (Communication from *G. Schroeter*: comp. also B. **38**, 3389):



$$NaCH(SO_2NR_2)_2 \xrightarrow{C_2H_5I} C_2H_5CH(SO_2NR_2)_2 \longrightarrow \underset{\text{Ethyl Methionic Acid.}}{C_2H_5CH(SO_3H)_2}$$

$$CH_3CNa(SO_2NR_2)_2 \xrightarrow{C_2H_5I} \begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>C.(SO_2NR_2)_2 \longrightarrow \underset{\substack{\text{Ethyl Methyl}\\ \text{Methionic Acid.}}}{\begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>C(SO_3H)_2}$$

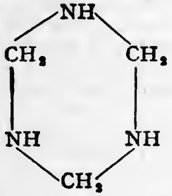
Ethylidene Disulphonic Acid, *Methyl Methionic Acid*, $CH_3CH(SO_3H)_2$, is also formed from thialdine (p. 209) by oxidation with permanganate (B. **12**, 682; **21**, 1550).

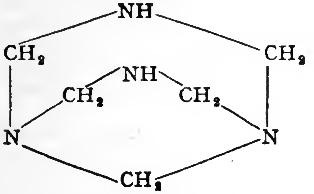
4. NITROGEN DERIVATIVES OF THE ALDEHYDES

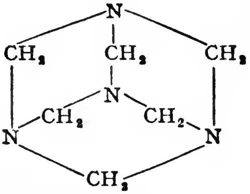
A. **Nitro-Compounds.**—*Bromonitromethane*, and 1,1-*Bromonitroethane* and *-propane*, as well as 1,1-*Dinitroparaffins* (p. 154), *diisonitramines* (p. 154) and the salts of the *aci*-nitroparaffins (p. 150), which have been previously described, must be regarded as nitrogen derivatives of aldehyde.

B. **Ammonia and Monalkylamine Aldehyde Derivatives** (p. 195).—Whilst ammonia combines with acetaldehyde and its homologues, forming aldehyde-ammonias or amido-alcohols, *e.g.*, $CH_3.CH{<}\begin{matrix}NH_2\\OH\end{matrix}$, when it comes into contact with formaldehyde it immediately produces.

Hexamethylene Tetramine, *Urotropin* $(CH_2)_6N_4$, which is known under the name of *formin*, is a solvent for uric acid. It is very soluble in water, and crystallizes from alcohol in brilliant rhombohedra. It sublimes without decomposition under reduced pressure. It is resolved into CH_2O and ammonia when distilled with sulphuric acid. It is a monacid base, but shows no reaction with litmus (B. **22**, 1929). Efforts have been made to ascertain its molecular weight by the analysis of its salts, by an approximate determination of its vapour density, and by the lowering of the freezing point of its aqueous solution (B. **19**, 1842; **21**, 1570). Nitrous acid first converts hexamethylene tetramine into dinitrosopentamethylene tetramine, and this then into trinitrosotrimethylene triamine. When it is considered that trimethylene trimethyl triamine is formed by the interaction of methylamine and formaldehyde, it is obvious that the reaction must cease at this point, because the imide-hydrogen atoms have been replaced by methyl groups. Ammonia and formaldehyde yield at first trimethylene triamine, corresponding with trimethylene trimethyl triamine, which absorbs ammonia and formaldehyde, splits off water and becomes pentamethylene diamine. The latter is converted by formaldehyde into hexamethylene tetramine. The following constitutional formulæ aim to represent this behaviour (comp. *Roscoe* and *Schorlemmer* (1884), vol. III. 646; *Duden* and *Scharff*, A. **288**, 218; see also C. 1898, I. 36):


Trimethylene Triamine.


Pentamethylene Tetramine.


Hexamethylene Tetramine.

Hexamethylene tetramine forms addition compounds with bromine, iodine, iodoalkyls and iodine, mercuric iodide and iodine, chloral and bromal (C. 1898, II. 663; 1900, I. 409):

$(CH_2)_6N_4I_4$, $(CH_2)_6N_4I_2.CH_3I$, $(CH_2)_6N_4I_2.2HgI_2$, $(CH_2)_6N_4.CCl_3CHO+2H_2O$.

When heated with hydrochloric or acetic acid urotropin is decomposed respectively into formaldehyde and ammonia or into *methylamine* and CO_2 (C. 1906, I. 1088). Compare the formation of trimethylamine by heating formaldehyde with ammonium salts (p. 158).

The following bodies are produced when primary amines act on formaldehyde (B. **28**, R. 233, 381, 924; **29**, 2110):

Methyl Methylene Amine, $[CH_2{=}N.CH_3]_3$, b.p. 166°; $D_{18\cdot7} = 0\cdot9215$.

Ethyl Methylene Amine, $[CH_2{=}N.C_2H_5]_3$, b.p. 207°; $D_{18\cdot7} = 0\cdot8923$.

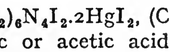
n-Propyl Methylene Amine, $[CH_2{=}N.C_3H_7]_3$, b.p. 248°; $D_{18\cdot7} = 0\cdot880$.

The hydroiodides of methyl and ethyl methylene amines are converted by heat into isomeric salts possessing the characteristics of quaternary ammonium salts, as is perhaps represented by the following formulæ (A. **334**, 210):

$$[(CH_2)_3(NR)_3]HI \text{ and } [(CH_2)_3(N_3R_2H)]RI.$$

By the use of aldehydes of higher molecular weight, the tendency to polymerization on the part of the reaction products of primary amines and aldehydes diminishes:

Methyl Isobutylene Amine, $(CH_3)_2CH.CH{=}N.CH_3$, b.p. 68°. Secondary amines and formaldehyde yield—

Tetramethyl Methylene Diamine,  $CH_2{<}^{N(CH_3)_2}_{N(CH_3)_2}$, b.p. 85° (B. **26**, R. 934; B. **36**, 1196).

Aldehyde bisulphites (p. 207) react with ammonia and primary or secondary amines to form sulphurous acid esters of the aldehyde ammonias (B. **37**, 4087; **38**, 1077). They also result from the action of sodium bisulphite on alkylidine imines.

Aminomethyl Sulphurous Ester, $NH_2CH_2.OSO_2H$, forms crystals soluble with difficulty in water. *Diethyl Aminomethyl Sodium Sulphite*, $(C_2H_5)_2NCH_2.OSO_2Na$, yields tetraethyl methylene diamine when heated with hydrochloric acid or potassium hydroxide solution. With acetic anhydride it forms *Diethyl Aminomethylene Acetate*, $(C_2H_5)_2NCH_2.OCOCH_3$, b.p.$_{14}$ 81°. Potassium cyanide in aqueous solution changes it to diethyl aminoacetonitrile $(C_2H_5)_2N.CH_2CN$.

Aldehyde-ammonia, $CH_3CH(OH)NH_2$, m.p. 70–80°, is produced when dry ammonia gas is conducted into an ethereal solution of aldehyde, and consists of brilliant rhombohedra, dissolving readily in water. Acids resolve it into its components (p. 195):

$$CH_3.CHO \xrightarrow{NH_3} CH_3.CH(OH)NH_2 \xrightarrow{H_2SO_4} CH_3CHO + NH_4H.SO_4.$$

When kept for a long time *in vacuo* over sulphuric acid, the original crystals gradually change into gleaming white ones of *Ethylidenimine*, $(CH_3CH{=}NH)_3$, m.p. 85°, b.p. 123°. The *picrate*, recrystallized from alcohol, has the formula $(C_2H_5N)_3.C_6H_2(NO_2)_3OH + C_2H_5OH$ (C. 1899, I. 420).

In contact with water it passes into amorphous *Hydracetamide*, $C_6H_{12}N_2$. Sodium nitrite, added to a slightly acidified solution of aldehyde-ammonia, produces

Nitrosoparaldimine, $C_6H_{12}O_2(N.NO)$, which by reduction becomes *Aminoparaldimine*, $C_6H_{12}O_2(N.NH_2)$, and this in turn, by the action of dilute sulphuric acid, splits off *Hydrazine*, $NH_2.NH_2$ (B. **23**, 740). Paraldimine should be viewed as paraldehyde in which an oxygen atom has been replaced by the imino-group. Hydrogen sulphide changes aldehyde-ammonia to *Thialdine* (p. 209), whilst with hydrocyanic acid it becomes the nitrile of *a-amidopropionic acid* (*q.v.*). A rather remarkable reaction occurs when aldehyde-ammonia acts on acetoacetic ester, resulting in the formation of 1,3,5-*Trimethyl Dihydropyridine Dicarboxylic Ester* (Vol. II.).

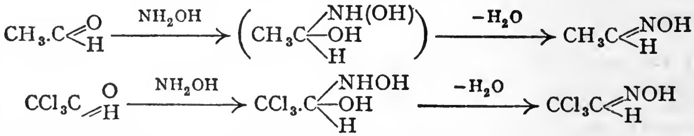
Hexaethylidene Tetramine, $(CH_3CH)_6N_4$, m.p. 102°, with $6H_2O$, m.p. 96°, is obtained by heating aldehyde-ammonia with aqueous ammonia to 150° (C. 1900, I. 901).

Chloral-ammonia, $CCl_3CH{<}\genfrac{}{}{0pt}{}{NH_2}{OH}$, m.p. 63°.

For the *chloralimides*, $(CCl_3.CH:NH)_3$, and *Dehydrochloralimides*, $C_6H_4Cl_9N_3$, consult B. **25**, R. 794; **24**, R. 628. The isomerism of the former is very probably dependent upon the same causes as that of the polymeric thioaldehydes (p. 208).

C. Aldoximes, R′.CH=N.OH (*V. Meyer*, 1863).

The aldoximes are formed when hydroxylamine, in the form of an aqueous solution of hydroxylamine hydrochloride (1 mol.), mixed with an equivalent quantity of sodium hydroxide (½ mol.), acts in the cold on aldehydes. At first there is very evidently formed an unstable addition product, corresponding with aldehyde-ammonia, which in the case of chloral may be obtained in stable form, but which passes readily into the oxime:



$$CH_3.C{<}\genfrac{}{}{0pt}{}{O}{H} \xrightarrow{NH_2OH} \left(CH_3C\begin{array}{l}\diagup NH(OH)\\ -OH\\ \diagdown H\end{array}\right) \xrightarrow{-H_2O} CH_3C{<}\genfrac{}{}{0pt}{}{NOH}{H}$$

$$CCl_3C\genfrac{}{}{0pt}{}{O}{\diagup H} \xrightarrow{NH_2OH} CCl_3.C\begin{array}{l}\diagup NHOH\\ -OH\\ \diagdown H\end{array} \xrightarrow{-H_2O} CCl_3C{<}\genfrac{}{}{0pt}{}{NOH}{H}$$

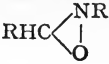
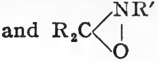
Aldoximes can also be obtained from primary amines by oxidation with permonosulphuric acid, H_2SO_5 (B. **35**, 4293). by reduction of *aβ*-nitroolefines (p. 151) with zinc and acetic acid (C. 1903, II. 553):

$$CH_3.CH_2NH_2 \xrightarrow{O} CH_3CH:NOH$$

$$(CH_3)_2C:CHNO_2 \xrightarrow{H} (CH_3)_2CH.CH:NOH$$

The aldoximes are colourless liquids which boil without decomposition. The first members of the series dissolve readily in water. When boiled with acids they are again changed to aldehyde and hydroxylamine. By the action of anhydrides or acid chlorides the aldoximes are converted into nitriles:

$$\underset{\textbf{Acetoxime.}}{CH_3CH{=}NOH} + (CH_3CO)_2O = \underset{\textbf{Acetonitrile.}}{CH_3C \equiv N} + 2CH_3CO_2H.$$

The oximes and hydrazones (see below), like the aldehydes, take up hydrocyanic acid; the products are amidoxyl- or hydrazino-nitriles (B. **29**, 62). By the direct action of alkyl halides on aldoximes and ketoximes only alkyl-nitrogen compounds of the *Isoximes* (Vol. II.) are formed,  $RHC<\begin{smallmatrix}NR'\\|\\O\end{smallmatrix}$ and  $R_2C<\begin{smallmatrix}NR'\\|\\O\end{smallmatrix}$ (C. 1901, I. 1147).

Formoxime, *Formaldoxime,* $CH_2=N.OH$, b.p. 84°, passes spontaneously into polymeric **triformoxime,** $CH_2<\begin{smallmatrix}N(OH).CH_2\\N(OH).CH_2\end{smallmatrix}>N.OH$ (B. **29**, R. 658). Formoxime yields hydrocyanic acid when it is boiled with water (B. **28**, R. 233; C. 1898, II. 18).

Acetaldoxime, $CH_3.CH:NOH$, m.p. 47°, b.p. 115°, also exists in a second modification, m.p. 12°, which readily reverts to the first form (B. **26**, R. 610; **27**, 416; **40**, 1677; C. 1898, II. 178). Chlorine in hydrochloric acid solution converts it into chloronitrosoethane, $CH_3CHClNO$ (p. 153), which easily becomes rearranged into $CH_3CCl:NOH$.

Chloral Hydroxylamine, $CCl_3.CH(OH)NH(OH)$, m.p. 98° (B. **25**, 702), even upon standing in the air, becomes converted into

Chloraloxime, $CCl_3CH=NOH$, m.p. 39–40°.

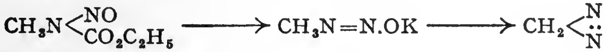
Propionaldoxime, $C_2H_5.CH=N.OH$, b.p. 130–132°.

Isobutyraldoxime, $(CH_3)_2CH.CH=NOH$, b.p. 139°. *Isovaleraldoxime,* $(CH_3)_2CH.CH_2.CH=NOH$, b.p. 164–165°. *Œnanthaldoxime,* $CH_3(CH_2)_5CH:NOH$, m.p. 55·5°, b.p. 195°. *Myristin Aldoxime,* m.p. 82° (B. **26**, 2858).

The aldoximes of the fatty series resemble the aromatic *syn*-aldoximes in their behaviour (B. **28**, 2019).

D. **Diazoparaffins** are produced, as shown by *v. Pechmann* in 1894, by the action of alkalis on nitrosamines. Diazomethane alone has been carefully studied.

Diazomethane, *Azimethylene,* CH_2N_2, is best prepared by the action of alkalis on nitrosomethyl urethane in ether solution, when the alkali methyl-azoate is formed as an intermediate product which yields diazomethane by the action of water (B. **35**, 897):



$$CH_3N<\begin{smallmatrix}NO\\CO_2C_2H_5\end{smallmatrix} \longrightarrow CH_3N=N.OK \longrightarrow CH_2<\begin{smallmatrix}N\\\vdots\\N\end{smallmatrix}$$

Diazomethane is also formed from methyl dichloramine and hydroxylamine (p. 167); compare also B. **29**, 961). At the ordinary temperature it is a yellow, odourless, and very poisonous gas, which strongly attacks the skin, the eyes, and the lungs.

Diazomethane exhibits the reactivity of diazoacetic ester (*q.v.*). Water converts it into methyl alcohol. Iodine changes it to methylene iodide. Inorganic and organic acids are changed into their methyl esters: hydrochloric acid into methyl chloride; hydrocyanic acid into acetonitrile; phenols into anisols; toluidine into methyl toluidine.

Aldehydes transform it into alkyl methyl ketones (p. 217). Diazomethane unites with acetylene to form pyrazole, and with ethylene to form pyrazoline (C. 1905, II. 1236). With methyl fumarate it forms pyrazoline dicarboxylic ester (B. **28**, 624, 2377; **31**, 2950). For its behaviour with quinones, compare B. **32**, 2292. On the dissociation of diazomethane into $(CH_2)_x$ and nitrogen, see B. **33**, 956.

E. Aldehyde Hydrazones (*E. Fischer*, A. 190, 134; 236, 137).

The *aldehyde hydrazones* correspond with the *aldoximes*. They are the transposition products of aldehydes and *hydrazines* (*q.v.*), which are formed when their constituents are mixed in ethereal solution:

$$CH_3CHO+H_2N.NHC_6H_5 = CH_3CH=N.NHC_6H_5+H_2O.$$

Acetaldehyde Hydrazone, *Ethylidene Phenylhydrazine,* $CH_3.CH=NNHC_6H_5$, b.p.$_{20}$ 140°; α-form, m.p. 98–101°; β-form, m.p. 75°, forms a white crystalline mass which is very sensitive towards acids. When recrystallized from 75 per cent. alkaline alcohol the α-modification is obtained; if it is recrystallized from 75 per cent. alcohol containing SO_2 the labile β-modification is deposited, which gradually changes into the α-form. The two modifications are identical in structure, and are stereoisomerically connected (p. 32) (A. **342**, 15). Structurally isomeric with this compound is *Phenyl Azoethyl*, $C_6H_5N:N.CH_2CH_3$ (Vol. II.), which is transformed into acetaldehyde hydrazone by solution in cold concentrated sulphuric acid (B. **29**, 793). Aldehyde precipitates a *compound*, $CH_3.CHO.\text{-}2(C_6H_5NHNH_2)$, m.p. 77·5°, from the solution of phenylhydrazine bitartrate (B. **29**, R. 596).

Propylaldehyde Phenylhydrazone, $CH_3.CH_2.CH{=}N_2C_6H_5$, b.p.$_{180}$ 205°. These hydrazones take up hydrocyanic acid and pass into the nitriles of hydrazido-acids (B. **25**, 2020).

Formaldehyde differs from the higher homologues in that with phenylhydrazine it yields—

Trimethylene Phenylhydrazine, $(C_6H_5N_2)_2(CH_2)_3$, b.p. 183–184° (B. **29**, 1473; R. 777).

Formalazine, $(CH_2{=}N{-}N{=}CH_2)_x$, is a white amorphous powder insoluble in water. *Formalhydrazine*, $(CH_2:N.NH_2)_3$ is a water-insoluble powder, which gives a double compound with silver nitrate $(CH_2:NNH_2)_3.2ANOg_3$. It results under various conditions from formaldehyde and hydrazine hydrate (B. **26**, 2360; **40**, 1505).

Ethylidene Azine, $CH_3CH:N.N:CHCH_3$; b.p. 95° (J. pr. Ch. [2] **58** 325).

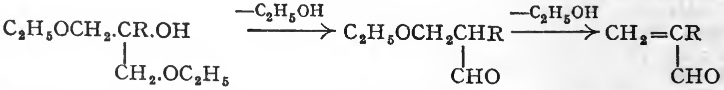
2B. OLEFINE ALDEHYDES, $C_nH_{2n-1}.CHO$

The unsaturated aldehydes, having a double carbon bond, bear the same relation to the olefine alcohols (p. 123) that the saturated aldehydes sustain to their corresponding alcohols. Their aldehyde group shows the same reactive power as the group in the ordinary aldehydes, but the presence of the unsaturated residue, C_nH_{2n-1}, gives rise to addition-reactions similar to those shown by the olefines. αβ-Olefine aldehydes result from the following special methods:

(1) By the condensation of aldehydes of the formula $RCH_2.CHO$ by zinc chloride, hydrochloric acid, etc., during which water is split off from the aldol first formed.

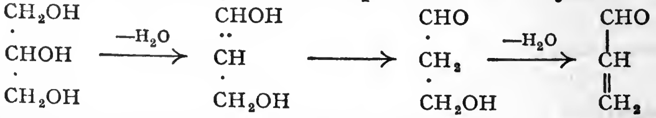
$$\underset{\text{Acetaldehyde.}}{2CH_3CHO} \longrightarrow \underset{\text{Aldol.}}{CH_3CHOH.CH_2CHO} \longrightarrow \underset{\text{Croton Aldehyde.}}{CH_3CH:CHCHO}$$

(2) From glycerol (see Acroleïn) and from the dialkyl ethers of homologous glycerols, by heating with anhydrous oxalic acid, accompanied by the expulsion of water or alcohol, similarly to the formation of paraffin aldehydes from ethylene glycol ethers (p. 192; A. chim. phys. [8] **9**, 560)



$$\underset{CH_2.OC_2H_5}{C_2H_5OCH_2.\overset{|}{C}R.OH} \xrightarrow{-C_2H_5OH} \underset{CHO}{C_2H_5OCH_2\overset{|}{C}HR} \xrightarrow{-C_2H_5OH} \underset{CHO}{CH_2{=}\overset{|}{C}R}$$

Acroleïn, $CH_2:CH.CHO$, b.p. 52°, $D_{20} = 0·8410$, is produced by the oxidation of allyl alcohol and by the distillation of glycerol or fats (1 pt.) with potassium bisulphate (2 pts.) (B. **20**, 3388; A. Spl. **3**, 180; C. 1900, I. 962; B. **35**, 1137), or with boric acid (B. **32**, 1352; C. 1905, II. 302); and also by the decomposition of fats by heat:



$$\begin{matrix}CH_2OH\\ \cdot\\ CHOH\\ \cdot\\ CH_2OH\end{matrix} \xrightarrow{-H_2O} \begin{matrix}CHOH\\ \cdot\cdot\\ CH\\ \cdot\\ CH_2OH\end{matrix} \longrightarrow \begin{matrix}CHO\\ \cdot\\ CH_2\\ \cdot\\ CH_2OH\end{matrix} \xrightarrow{-H_2O} \begin{matrix}CHO\\ |\\ CH\\ \|\\ CH_2\end{matrix}$$

Acroleïn is a colourless, mobile liquid, and has an intolerably pungent odour. It is soluble in 2–3 parts water, and reduces an ammoniacal silver solution, with formation of a mirror-like deposit; when exposed to the air it becomes oxidized to acrylic acid. It does not combine with primary alkali sulphites. Nascent hydrogen converts it into *allyl alcohol* (p. 123).

Acroleïn Acetal, $CH_2:CH.CH(OC_2H_5)_2$, b.p. 123°, is formed by the action of powdered potassium hydroxide on chloropropionaldehyde acetal, which is prepared from acroleïn by means of alcohol and hydrochloric acid (B. **31,** 1797) (see Glyceric aldehyde).

Phosphorus pentachloride converts acroleïn into *dichloropropylene*, $CH_2:CH.CHCl_2$, b.p. 84°. With hydrochloric acid it yields *β-chloropropionaldehyde* (p. 203). With bromine it yields a dibromide, $CH_2.Br.CHBr.CHO$, which becomes converted into glyceric aldehyde when heated with water, and into *aβ-dibromopropionic acid* upon oxidation with nitric acid. Barium hydroxide solution converts it into *a-acrose* or (d+l) *fructose* (*q.v.*) (B. **20,** 3388).

When kept for some length of time, acroleïn passes into an amorphous, white mass (*disacryl*). On warming the HCl compound of acroleïn (see above) with alkalis or potassium carbonate *metacroleïn*, m.p. 45°, is obtained. The vapour density of this agrees with the formula $(C_3H_4O)_3$.

Ammonia changes acroleïn into *acroleïn-ammonia*, $2C_3H_4O+NH_3=C_6H_9NO+H_2O$. This is a yellowish mass which on drying becomes brown, and forms amorphous salts with acids. It yields *picoline*, $C_5H_4N.CH_3$ (*q.v.*), when distilled. Hydrazine changes acroleïn to pyrazoline, and phenylhydrazine converts it into 1-phenylpyrazoline (B. **28,** R. 69).

Crotonaldehyde, $CH_3.CH:CH.CHO$, b.p. 104°, $D = 1{\cdot}033$ (*Kekulé*, A. **162,** 91), is obtained by the condensation of *acetaldehyde* (p. 199) from the primarily formed *aldol* by heating it with dilute hydrochloric acid, with water and zinc chloride, or with a sodium acetate solution, to 100° (B. **14,** 514; **25,** R. 732). When aldol is heated or treated with dilute hydrochloric acid it loses water and becomes converted into crotonaldehyde (p. 197; C. 1907, I. 1400).

Crotonaldehyde is a liquid with an irritating odour; it becomes oxidized by the air to crotonic acid, and it reduces silver oxide (B. **29,** R. 290). It combines with hydrochloric acid to form *β-chlorobutyraldehyde* (p. 203); on standing with hydrochloric acid it unites with water and becomes *aldol*. Iron and acetic acid reduce it to *crotonyl alcohol, butyraldehyde* and *butyl alcohol*.

When the alcoholic solution of acetaldehyde-ammonia is heated to 120°, **Crotonal-ammonia,** *Oxytetraldine*, $C_8H_{13}NO$, is produced. It is a brown, amorphous mass. When heated it breaks up into water and *collidine*, $C_5H_2N(CH_3)_3$, a pyridine derivative (Vol. II.).

Tiglic Aldehyde, *Guaiol*, $CH_3CH=C(CH_3).CHO$, b.p. 116°, may be obtained by the distillation of guaiacol resin, and by the condensation of acetaldehyde and propaldehyde.

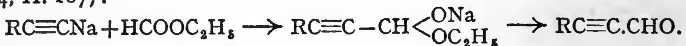
Methyl Ethyl Acroleïn, $C_2H_5.CH:C(CH_3).CHO$, b.p. 137°, is produced by the condensation of propionaldehyde (p. 201).

a-Propyl Acroleïn, b.p. 117°, *Isobutyl Acroleïn*, b.p. 133°, and *Amyl Acroleïn*, b.p.$_{13}$ 59°, $CH_2:CR.CHO$, are prepared from the respective glycerol ethers (method of formation 2, p. 214).

Citronellal and its isomer **Rhodinal** are olefine aldehydes, and **Geranial** or **Citral** belongs to the class of diolefine aldehydes. These will be duly considered under the *olefine terpenes* (Vol. II.).

2 C. **Acetylene Aldehydes,** $C_nH_{2n-3}.CHO$. **Propargylic Aldehyde,** $CH\vdots C.CHO$, b.p. 59°, is produced when the *acetal*, $CH\vdots C.CH(OC_2H_5)_2$, b.p. 140°, formed from dibromacroleïn acetal and alcoholic potassium hydroxide, is boiled with dilute sulphuric acid. It is a very mobile liquid, which provokes tears. Its *silver salt* is very explosive. Sodium hydroxide at the ordinary temperature decomposes propargylic aldehyde instantly into acetylene and sodium formate: $CH\vdots C.CHO+NaOH=CH\vdots CH+NaO.CHO$ (*Claisen*, B. **31,** 1021).

Homologous acetylene aldehydes or their *acetals* are obtained from the sodium or magnesium haloid salts of acetylene (pp. 88, 184) by the addition of formic or orthoformic esters (mode of formation No. 9, of the aldehydes, p. 192; C. 1904, II. 187):



$$RC{\equiv}CNa + HCOOC_2H_5 \longrightarrow RC{\equiv}C-CH\!<\!\begin{matrix}ONa\\OC_2H_5\end{matrix} \longrightarrow RC{\equiv}C.CHO.$$

$$RC{\equiv}CMgI + HC(OC_2H_5)_3 \longrightarrow RC{\equiv}C.CH(OC_2H_5)_2 \longrightarrow RC{\equiv}C.CHO.$$

Amyl Propiolic Aldehyde, $C_5H_{11}C{\equiv}C.CHO$, b.p.$_{26}$ 89°, *Acetal*, b.p.$_{11}$ 110°, and *Hexyl Propriolic aldehyde*, $C_6H_{13}C{\equiv}C.CHO$, b.p.$_{13}$ 91°, *Acetal*, b.p.$_{12}$ 127°, are prepared in this way from œnanthylidene and caprylidene, respectively.

These acetylene aldehydes do not yield the anticipated oximes and hydrazones with hydroxylamine and hydrazine, but their internal condensation compounds, such as *isoxazole* and *pyrazole* (B. **36**, 3665; C. 1904, II. 187):

$$CH{:}CH.CH{:}NO \xleftarrow{NH_2OH} CH{\equiv}C.CHO \xrightarrow{NH_2NH_2} CH{:}CH.CH{:}N.NH.$$

Isoxazole. Propiolic Aldehyde. Pyrazole.

3 A. Ketones of the Saturated Series, Paraffin Ketones, $C_nH_{2n}O$

In the introduction to the aldehydes and ketones (p. 189) attention was directed to the great similarity between these two classes of compounds, which finds expression in their most important methods of formation and in their transposition reactions. It was also stated that two different kinds of ketones were known:

1. *Simple ketones*, containing two similar alkyl groups.
2. *Mixed ketones*, having two different alkyl groups.

Methods of Formation.—(1) Oxidation of secondary alcohols, whereby the =CH.OH-group is converted into the =CO-group (p. 190).

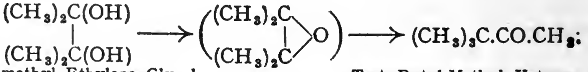
(2) From such derivatives as oximes, hydrazones, semicarbazones, ketonic chlorides, comparably to method 6 for the aldehydes (p. 192):

$$(CH_3)_2CCl_2 \xrightarrow[100°]{H_2O} [(CH_3)_2C.(OH)_2] \longrightarrow (CH_3)_2CO.$$

(3) The transformation of di-primary, primary-secondary and primary-tertiary glycols and ethylene oxides into aldehydes by means of hydrochloric or sulphuric acids (method 7, p. 192) corresponds with the change of secondary-tertiary and di-tertiary glycols into ketones (C. 1906, II. 670):

$$\underset{\text{Diethylmethyl Ethylene Glycol.}}{(C_2H_5)_2C(OH).CH(OH)CH_3} \xrightarrow{H_2SO_4} \underset{\text{Unsym.-Diethylacetone.}}{(C_2H_5)_2CH.COCH_3}$$

The change of di-tertiary glycols, known as *pinacones*, into ketones or *pinacolines* is accompanied by the migration of an alkyl group. The simplest of the di-tertiary glycols is *Tetramethyl Glycol*, or *Pinacone*, from which the abstraction of water should produce tetramethyl ethylene oxide. Instead, this substance becomes rearranged internally to form the simplest *pinacoline tert.-butyl methyl ketone*:—



$$\begin{matrix}(CH_3)_2C(OH)\\|\\(CH_3)_2C(OH)\end{matrix} \longrightarrow \left(\begin{matrix}(CH_3)_2C\\|\\(CH_3)_2C\end{matrix}\!\!>\!O\right) \longrightarrow (CH_3)_3C.CO.CH_3:$$

Tetramethyl Ethylene Glycol. Pinacone. Tert.-Butyl Methyl Ketone: Pinacoline.

(4) By action of acids (B. **29**, 202) on the sodium salts of the mononitroparaffins (pp. 150, 151), in which the nitro-group is attached to a terminal carbon atom:

$$2(CH_3)_2C : NOONa + 2HCl = 2(CH_3)_2CO + N_2O + 2NaCl + H_2O.$$

(5) By hydrolysis of the ethers of $\alpha\beta$-olefine alcohols (p. 129); C. 1904, I. 719):

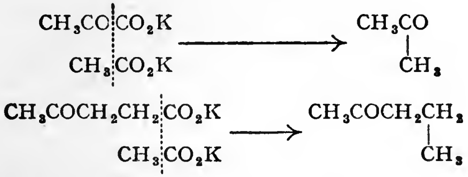
$$C_5H_{11}C(OCH_3) : CH_2 \xrightarrow[H_2SO_4]{dilute} C_5H_{11}.COCH_3 + CH_3OH.$$

Nucleus-synthetic Methods of Formation.—(6) By the distillation of calcium or barium acetates and their higher homologues. Such a salt, when heated alone, yields a *simple ketone*, but a mixture of equimolecular quantities of the salts of two acids results in the formation of *mixed ketones* (p. 190).

In the formation of ketones with high molecular weight it is best to carry out the distillation under diminished pressure. Some normal fatty acids yield ketones on treatment with P_2O_5 (B. **26**, R. 495).

Recently it has been recommended to distil the acids with calcium carbide (B. **39**, 1703).

(7) By the electrolysis of a mixture of the potassium salts of a keto-carboxylic and a fatty acid:

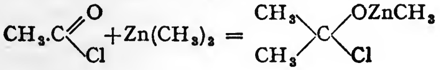


$$\begin{matrix}CH_3CO\,\vdots\,CO_2K\\ CH_3\,\vdots\,CO_2K\end{matrix} \longrightarrow \begin{matrix}CH_3CO\\ |\\ CH_3\end{matrix}$$

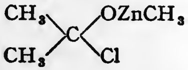
$$\begin{matrix}CH_3COCH_2CH_2\,\vdots\,CO_2K\\ CH_3\,\vdots\,CO_2K\end{matrix} \longrightarrow \begin{matrix}CH_3COCH_2CH_2\\ |\\ CH_3\end{matrix}$$

(8) By the action of the zinc alkyls on the acid chlorides (*Freund*, 1860).

The reaction is similar to that occurring in the formation of the tertiary alcohols (p. 105). At first the same intermediate product is produced (A. **175**, 361; **188**, 104):

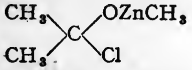


which (with a second molecule of the acid chloride) afterwards yields the ketone and zinc chloride:



$+CH_3.COCl = 2CH_3.CO.CH_3+ZnCl_2.$

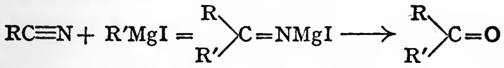
In many cases, especially in the preparation of the ordinary *pinacoline* from trimethyl acetyl chloride and zinc methyl, it is preferable to decompose immediately the addition product of zinc methyl and acid chloride with water, when the zinc hydroxide will be converted by the hydrochloric acid into zinc chloride:



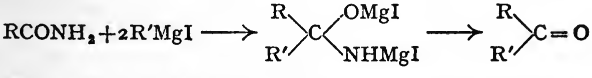
$+2H_2O = CH_3.CO.CH_3+Zn(OH)_2+HCl+CH_4.$

(9) By the action of alkyl magnesium halides, ketones as well as aldehydes (mode of formation 9, p. 192) can be prepared, (*a*) by their action on nitriles, and (*b*) on acid amides (C. 1902, I. 299; 1903, II. 1110).

(*a*)



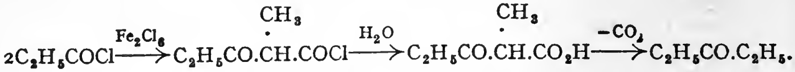
(*b*)



(10) By the action of diazomethane (p. 213), the aldehydes can be converted into alkyl methyl ketones (B. **40**, 481):

$$C_6H_{13}COH+CH_2N_2=C_6H_{13}CO.CH_3+N_2.$$

(11) By the action of anhydrous ferric chloride on the acid chlorides. Hydrochloric acid is set free, and chlorides of β-ketone-carboxylic acids are produced. From these water liberates the free β-ketone-carboxylic acids. The latter break down readily into carbon dioxide and ketones:

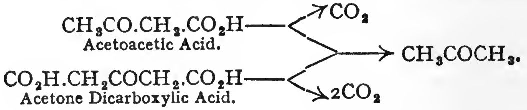


$$2C_2H_5COCl \xrightarrow{Fe_2Cl_6} C_2H_5CO.\overset{CH_3}{\overset{\cdot}{C}H}.COCl \xrightarrow{H_2O} C_2H_5CO.\overset{CH_3}{\overset{\cdot}{C}H}.CO_2H \xrightarrow{-CO_2} C_2H_5CO.C_2H_5.$$

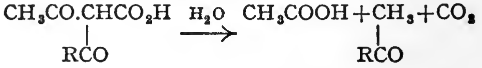
(12) *Degradation Methods of Formation.*—By the oxidation of dialkyl acetic acids, and the α-hydroxydialkyl acetic acids corresponding with them; the latter are simultaneously formed as intermediate products in the oxidation of the former compounds, *e.g.*:

$$(CH_3)_2CH.CO_2H \xrightarrow{O} (CH_3)_2C(OH).CO_2H \xrightarrow{O} (CH_3)_2CO + CO_2 + H_2O.$$

(13) By the breaking down of β-ketone-mono- and dicarboxylic acids—*e.g.*:



Compare acetoacetic ester, and also its homologues, such as acetone dicarboxylic acid. Acyl acetoacetic acid breaks down in a similar way, forming ketones, as well as carboxylic acids, with liberation of CO_2 (C. 1903, I. 225):



$$\underset{RCO}{CH_3CO.\underset{|}{C}HCO_2H} \xrightarrow{H_2O} CH_3COOH + \underset{RCO}{\underset{|}{CH_3}} + CO_2$$

The ketones are produced in the dry distillation of citric acid, sugar, cellulose (wood), and of many other carbon compounds, so that they are found in coal and coal-tar (B. **36**, 254, 2713).

Nomenclature and Isomerism.—The term ketone is derived from the simplest and first discovered ketone—*acetone*. The names of the ketones are obtained by associating the names of the alkyls with the word *ketone*—*e.g.* dimethyl ketone, methyl ethyl ketone, etc.

A. Baeyer regards the ketones as keto-substitution products of the hydrocarbons, and the group CO, uniting two alkyl groups, he terms the keto-group. As one carbon atom in the name ketopropane would, in consequence of this suggestion, be twice designated, *Kekulé* has suggested that the oxygen linked doubly to carbon be called "oxo"-oxygen. Then acetone, CH_3COCH_3, would be 2-*oxopropane*, propionic aldehyde, $CH_3.CH_2.CHO$, would be 1-*oxopropane*. The "Geneva names" are obtained by adding the suffix "one" to the name of the hydrocarbon: acetone is called [Propanone], and methyl ethyl ketone is [Butanone].

As there is a ketone for every secondary alcohol, the number of isomeric ketones of definite carbon content is equal to the number of possible secondary alcohols containing the same number of carbon atoms. The *simple ketones* are isomeric with the *mixed ketones* having a like carbon content. The isomerism of the ketones among themselves is dependent upon the homology of the alcohol radicals united with the CO-group. (Consult the isomerism of the aldehydes (p. 193) for the isomerism of the ketones with other compounds.)

Properties and Reactions.—The ketones are neutral bodies. The lower members of the series are volatile, ethereal-smelling liquids, whilst the higher members are solids.

In enumerating the reactions of the ketones, it will be best to examine *acetone*, the most important and most thoroughly investigated member of this class of bodies.

1. Ketones differ chiefly from aldehydes in their behaviour when oxidized. They are not capable of reducing an alkaline silver solution, and are not so easily oxidized as the aldehydes.

When the more powerful oxidants are employed, the ketones almost invariably break down at the union with the CO-group—carboxylic acids are produced, and in some cases ketones with a lower carbon content:

$$CH_3.CO.CH_3 \longrightarrow CH_3.CO_2H \text{ and } H.CO_2H \xrightarrow{O} CO_2+H_2O$$
$$C_2H_5.CO.C_2H_5 \longrightarrow C_2H_5.CO_2H \text{ and } CH_3.CO_2H.$$

In the case of mixed ketones, when both alcohol radicals are primary in character, the CO-group does not, as was formerly supposed, remain exclusively with the lower alcohol radical, but the reaction proceeds in both possible directions, *e.g.*:

$$CH_3CH_2.CO.CH_2CH_2CH_3 - \begin{array}{l} \nearrow CH_3.CO_2H \text{ and } CO_2H.CH_2CH_2CH_3 \\ \searrow 2CH_3CH_2.CO_2H \end{array}$$

When a secondary alcohol radical is present it splits off as ketone, and is then further oxidized, whilst with a tertiary alcohol radical the CO-group remains combined as carboxyl.

The direction in which the oxidation proceeds is dependent less upon the oxidizing agent than upon the oxidation temperature (A. **161**, 285; **186**, 257; B. **15**, 1194; **17**, R. 315; **18**, 2266, R. 178; **25**, R. 121).

It is remarkable that *pinacoline* (p. 216) is successfully oxidized by potassium permanganate to the corresponding α-ketone-carboxylic acid of like carbon content: *trimethyl pyroracemic acid*:

$$\underset{\text{Pinacoline.}}{(CH_3)_3C.CO.CH_3} \xrightarrow{3O} \underset{\text{Trimethyl Pyroracemic Acid.}}{(CH_3)_3C.CO.CO_2H.}$$

Hydrogen peroxide changes acetone into a peroxide (p. 224) which breaks up into *acetol*, CH_3COCH_2OH, and pyroracemic acid, $CH_3CO.COOH$ (C. 1905, II. 212).

2. Concentrated nitric acid converts the ketones in part into dinitro-paraffins (p. 154):

$$(C_2H_5)_2CO \xrightarrow{HNO_3} CH_3CH(NO_2)_2$$
$$(CH_3CH_2CH_2)_2CO \longrightarrow CH_3.CH_2CH(NO_2)_2$$

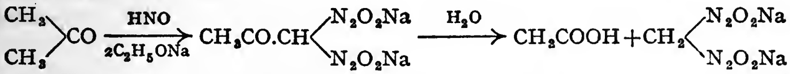
α-Diketones may be formed at the same time if the ketone be suitably constituted, *e.g.*, isopropyl isobutyl ketone (C. 1900, II. 124).

3. Amyl nitrite, in the presence of sodium ethoxide or hydrochloric acid, converts the ketones into *isonitroso-ketones*:

$$CH_3.CO.CH_3 \xrightarrow{C_5H_{11}NO_2} CH_3.CO.CH(NOH)$$
$$CH_3CO.CH_2.CH_3 \longrightarrow CH_3.CO.C(NOH).CH_3.$$

As *monoximes* of *α-keto-aldehydes*, or *α-diketones*, the isonitroso-ketones will be considered later in connection with both these classes of compounds.

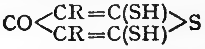
4. Ketones, containing the carbonyl group next to a methyl or methylene group, are acted on by nitrous oxide in presence of sodium ethoxide, and form the sodium salt of di-isonitramine ketones. These are decomposed by water into a carboxylic acid and the sodium salt of a *di-isonitramine alkylene* (p. 154; A. **300**, 95):



$$\begin{array}{l}CH_3\\CH_3\end{array}\!\!>CO \xrightarrow[2C_2H_5ONa]{HNO} CH_3CO.CH\!<\!\begin{array}{l}N_2O_2Na\\N_2O_2Na\end{array} \xrightarrow{H_2O} CH_3COOH+CH_2\!<\!\begin{array}{l}N_2O_2Na\\N_2O_2Na\end{array}$$

5. By the action of carbon disulphide and alkali hydroxide on ketones of the

formula RCH_2COCH_2R, there are produced orange-red coloured acids, probably of the following general formula (B. **38**, 2888):—



$$CO{<}\begin{matrix}CR{=}C(SH)\\CR{=}C(SH)\end{matrix}{>}S$$

Many of the addition reactions possible with ketones are due, as in the case of the aldehydes, to the ready destruction of the double union between carbon and oxygen. These reactions are partly followed, even with the ketones, by an immediate separation of water.

6. Nascent hydrogen (sodium amalgam, or electrolytic hydrogen, C. 1900, II. 795), converts the ketones into *secondary alcohols* (p. 105), from which they are produced by oxidation. *Pinacones*, or ditertiary glycols, are simultaneously formed (p. 216):

$$(CH_3)_2CO+2H=(CH_3)_2CH.OH;\quad 2(CH_3)_2CO+H_2=\begin{matrix}(CH_3)_2COH\\(CH_3)_2\dot{C}OH\end{matrix}$$

7. The ordinary ketones, like the ordinary aldehydes, do not combine with *water*, but when containing numerous halogen atoms, they unite with $4H_2O$ and $2H_2O$, forming hydrates.

8. The ketone derivatives, corresponding with the *acetals* (p. 205), are produced when the β-dialkoxycarboxylic acids, $RC(OC_2H_5)_2CH_2CO_2H$, lose CO_2, and by the interaction of ketones and orthoformic ester; or in general from imidoether hydrochlorides and alcohols (*Claisen*, B. **31**, 1010; B. **40**, 3021).

9. The ketones resemble the aldehydes in their behaviour—

a. with hydrogen sulphide;

b. with mercaptans in the presence of hydrochloric acid.

The products are *polymeric thioketones* (p. 225), and the *mercaptols, e.g.*, $(CH_3)_2.C(SC_2H_5)_2$, corresponding with the mercaptals (p. 209).

10. The ketones, unlike the aldehydes, do *not* combine with the acid anhydrides.

11. Only those ketones, which contain a methyl group, form crystalline compounds with the alkali bisulphites. These, like the corresponding aldehyde compounds, can be considered as salts of sulphurous acid esters:

$$(CH_3)_2CO+NaHSO_3=(CH_3)_2C{<}\begin{matrix}OH\\OSO_2Na\end{matrix}$$

These double salts are very suitable for the isolation and purification of the ketones, which can be liberated from them by dilute sulphuric acid or a sodium hydroxide solution.

12. Behaviour of ketones with *ammonia, hydroxylamine* and *phenylhydrazine.* (*a*) Acetone behaves differently towards ammonia from the aldehydes. Nucleus-synthetic reactions occur, with the formation of *diacetonamine* and *triacetonamine* (p. 230). Homologous ketones, however, react with ammonia according to the equation (C. 1905, II. 540; 1907, I. 810):

$$3R_2CO+2NH_3=(R_2C{=}N)_2CR_2+3H_2O.$$

With hydroxylamine, however, the ketones, like the aldehydes (p. 196), yield (*b*) *ketoximes* (p. 227), (*c*) with phenylhydrazine they form *hydrazones* (p. 228), and (*d*) with semicarbazide they give *semicarbazones* (p. 228).

13. When phosphorus trichloride acts on acetone in the presence of Al_2Cl_6, hydrochloric acid is set free, and there results the compound

$$\begin{matrix}&PCl{-}O\\&|\quad\;\;|\\CH_3.CO.&CH{-}C(CH_3)_2\end{matrix}$$

, m.p. 35°, b.p. 235° (B. **17**, 1273; **18**, 898).

14. *Phosphorus pentachloride, phosphorus trichloro-dibromide,* and *phosphorus pentabromide* replace the oxygen of the ketones by two chlorine or two bromine atoms.

This reaction can be employed for the preparation of dichloro- or dibromo-paraffins in which an intermediate C-atom carries the two halogen atoms. As these *ketone chlorides* readily exchange their chlorine for hydrogen, they constitute a means of converting the ketones into the corresponding paraffins (p. 74).

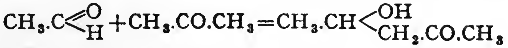
15. The hydrogen atoms of the alkyl groups present in the ketones can be replaced by chlorine and bromine.

16. Boiling with acid chlorides, especially benzoyl chloride, converts many ketones into esters of the isomeric $\alpha\beta$-olefine alcohols (p. 124), $RC(O.COC_6H_5):CHR'$.

17. Unlike the lower members of the aldehyde series which easily undergo polymerization, the ketones never do this. Compared with aldehydes the ketones possess a symmetrical structure.

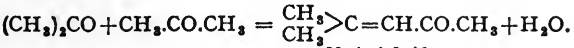
Nucleus-synthetic Reactions of the Ketones.—Reactions of this class were observed in the action of ammonia and of phosphorus trichloride on acetone in the presence of aluminium chloride (comp. 12 and 13). The following are, however, more important:—

(1) Just as two aldehyde molecules *condense* to *aldol*, so aldehyde or chloral will unite with acetone, forming *hydracetyl acetone* and *trichlorohydracetyl acetone* (*q.v.*):



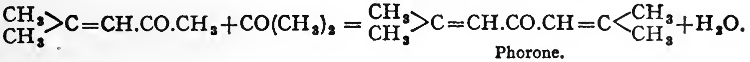
$$CH_3.C{<}^{O}_{H} + CH_3.CO.CH_3 = CH_3.CH{<}^{OH}_{CH_2.CO.CH_3}$$

Acetone will also condense with other aldehydes,—*e.g.*, benzaldehyde. But it is impossible to obtain the ketone-alcohols which form at first. There is a loss of water, and unsaturated derivatives are produced, just as in the condensation of two molecules of aldehyde to form *crotonaldehyde*. Thus, two molecules of acetone, in the presence of $ZnCl_2$,HCl, or H_2SO_4, unite directly, with the elimination of water, to form *mesityl oxide* (p. 229), which in turn condenses with a third molecule of acetone to form *phorone* (p. 229).



$$(CH_3)_2CO + CH_3.CO.CH_3 = {}^{CH_3}_{CH_3}{>}C{=}CH.CO.CH_3 + H_2O.$$

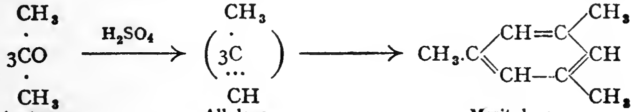
Mesityl Oxide.



$${}^{CH_3}_{CH_3}{>}C{=}CH.CO.CH_3 + CO(CH_3)_2 = {}^{CH_3}_{CH_3}{>}C{=}CH.CO.CH{=}C{<}^{CH_3}_{CH_3} + H_2O.$$

Phorone.

(2) Acetone and other ketones, having a suitable constitution, change into symmetrical trialkyl benzenes, under the influence of concentrated sulphuric acid. It is very probable that there is an intermediate formation of alkylated acetylenes (p. 89). Acetone yields *mesitylene*:



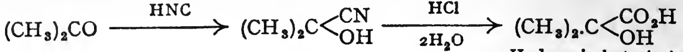
Acetone. Allylene. Mesitylene.

(3) Acetone condenses, in presence of lime or sodium ethylate, to *isophorone*, a trimethyl cyclo-hexenone (*q.v.*).

A sodium hydroxide solution at 0° causes two molecules of acetone to condense to *diacetone alcohol*, $(CH_3)_2C(OH).CH_2COCH_3$.

(4) The ketones, like the aldehydes, unite with hydrocyanic acid to form *hydroxycyanides* or *cyanhydrins*, the nitriles of the *a-hydroxy-acids*. They will

be described after the *a-hydroxy-acids,* into which they pass when treated with hydrochloric acid:



$$(CH_3)_2CO \xrightarrow{HNC} (CH_3)_2C<\begin{matrix}CN\\OH\end{matrix} \xrightarrow[2H_2O]{HCl} (CH_3)_2.C<\begin{matrix}CO_2H\\OH\end{matrix}$$

a-Hydroxyisobutyric Acid.

(5) Acetone, in the presence of sodium hydroxide, combines with chloroform, yielding *acetone chloroform,* which is a derivative of a-hydroxyisobutyric acid; the latter can be obtained from it:

$$(CH_3)_2CO \xrightarrow{CHCl_3} (CH_3)_2C<\begin{matrix}CCl_3\\OH\end{matrix} \longrightarrow (CH_3)_2C<\begin{matrix}CO_2H\\OH\end{matrix}$$

Acetone Chloroform. a-Hydroxyisobutyric Acid.

(6) Nascent hydrogen converts the ketones not only into secondary alcohols (p. 106), but also into pinacones, or di-tertiary glycols (p. 220):

Acetone, *Dimethyl Ketone* [Propanone], $CH_3.CO.CH_3$, m.p. $-94°$ (B. **33,** 638), b.p. 56·5°, $D_{20} = 0·7920$, is isomeric with *propionaldehyde, propylene oxide, trimethylene oxide,* and *allyl alcohol.* It occurs in small quantities in the blood and normal urine, whilst in the urine of those suffering from diabetes it is present in considerable amount, due, apparently, to the breaking down of the acetoacetic acid formed at first. It is also produced in the dry distillation of *tartaric acid, citric acid* (*q.v.*), *sugar, cellulose* (*wood*), and is, therefore, found in crude *wood spirit* (p. 109). Technically it is prepared by the distillation of calcium acetate, or from crude wood spirit.

It is also formed: by the oxidation of isopropyl alcohol, isobutyric acid, and *a*-hydroxyisobutyric acid; by heating chloracetol and bromacetol, $CH_3CBr_2CH_3$, with water to 160–180°; and β-chloro- and β-bromopropylene, $CH_3CBr{=}CH_2$, with water at 200°.

It would naturally be expected that an alcohol, $CH_3.C(OH):CH_2$, would be formed, but a transposition of atoms occurs and acetone results (see p. 36). Acetone is similarly formed from allylene, $CH_3.C \vdots CH$, by action of sulphuric acid or $HgBr_2$ in the presence of water (p. 89).

It results, further, in the action of zinc methyl on acetyl chloride; and, accompanied by diacetyl, by the electrolysis of a solution of pyroracemic acid and potassium acetate (B. **33,** 650. Acetone is also formed from a-bromoisobutyric amide by bromine and alkali (C. 1905, I. 1219):

$$(CH_3)_2CBr.CONHBr \xrightarrow{2KOH} (CH_3)_2CO + NH_3 + 2KBr + CO_2.$$

(See also the general methods of formation of the ketones, pp. 216, 217.)

Acetone is a mobile, peculiar-smelling liquid, and is miscible with water, alcohol, and ether. Calcium chloride, or potassium carbonate, throws it out from its aqueous solution.

It is an excellent solvent for many carbon compounds, and for many inorganic salts such as potassium permanganate, etc. (B. **37,** 4328). Its most important reactions were described under the reactions of the ketones (p. 218), as well as its behaviour towards nascent hydrogen, oxidizing agents, amyl nitrite, hydrogen sulphide, mercaptans and hydrochloric acid, alkali bisulphites, ammonia, hydroxylamine, phenylhydrazine, phosphorus pentachloride, halogens, condensation agents, hydrocyanic acid, chloroform, and potassium hydroxide. (See β-Allyl Alcohol, p. 124, for the action of sodium on acetone.)

Acetone is used in the preparation of *sulphonal* (p. 226), *chloroform* (p. 245), and *iodoform* (p. 246); the production of the latter serves for its detection (B. **13,** 1002; **14,** 1948; **17,** R. 503; **29,** R. 1006). (For other such reactions, consult B. **17,** R. 503; **18,** R. 195; A. **223,** 143.) Acetone can be quantitatively determined by means of mercuric sulphate (B. **32,** 986); also by heating it with mercuric acetate, whereby acetone-mercury substitution compounds are produced (B. **36,** 3699). Mercuric oxide dissolves in a weakly alkaline aqueous solution of acetone, forming the compound $2C_3H_6O.3HgO$ which by boiling with alkalis changes to the insoluble *Acetone Mercarbide,* $CH_3COCHg_3O_2H$ (B. **38,** 2677).

Homologues of Acetone.—(*a*) *Simple Ketones* are usually prepared by the distillation of the calcium or barium salts of the corresponding fatty acids.

Name.	Formula.	M. P.	B. P.
Diethyl Ketone, *Propione* [3-Pentanone]	$CO(C_2H_5)_2$	—	103°
Di-n-Propyl Ketone, *Butyrone* . . .	$CO(C_3H_7)_2$	—	144°
Di-isopropyl Ketone, *Tetramethyl Acetone*	$CO[CH(CH_3)_2]_2$	—	124°
Di-isobutyl Ketone, *Isovalerone* . .	$CO[CH_2CH(CH_3)_2]_2$	—	165°
n-Caprone	$CO(C_5H_{11})_2$	14·6°	226°
Tetraethyl Acetone	$CO[CH(C_2H_5)_2]_2$	—	203°
Œnanthone	$CO(C_6H_{13})_2$	30°	263°
Caprylone	$CO(C_7H_{15})_2$	40°	—
Caprinone	$CO(C_8H_{17})_2$	48°	—
Laurone	$CO(C_{11}H_{23})_2$	69°	—
Myristone	$CO(C_{13}H_{27})_2$	76°	—
Palmitone	$CO(C_{15}H_{31})_2$	83°	—
Stearone	$CO(C_{17}H_{35})_2$	88°	—

Diethyl Ketone is produced from carbon monoxide and potassium ethyl (p. 184). *Tetramethyl* and *Tetraethyl Acetone* have been obtained as decomposition products of *pentamethyl* and *pentaethyl phloroglucinol,* when these bodies were oxidized by air (B. **25,** R. 504).

(*b*) *Mixed Ketones.* Most of the members of this class are made by the distillation of the barium salts of the corresponding fatty acids with barium acetate (p. 217).

Name.	Formula.	M. P.	B. P.
Methyl Ethyl Ketone [Butanone] . .	$CH_3.CO.C_2H_5$	—	81°
Methyl Propyl Ketone [2-Pentanone] .	$CH_3.CO.C_8H_7$	—	102°
Methyl Isopropyl Ketone [Methyl Butanone]	$CH_3.CO.CH(CH_3)_2$	—	96°
Methyl sec.-Butyl Ketone	$CH_3.CO.CH_2CH(CH_3)_2$	—	116°
Pinacoline, *Methyl tert.-Butyl Ketone*	$CH_3.CO.C(CH_3)_3$	—	106°
Methyl Œnanthone *Methyl Hexyl Ketone*	$CH_3.CO.C_6H_{13}$	—	171°
Methyl Heptyl Ketone	$CH_3.CO.C_7H_{15}$	−15°	193°
Methyl Nonyl Ketone	$CH_3.CO.C_9H_{19}$	+15°	225°
Methyl Decyl Ketone	$CH_3.CO.C_{10}H_{21}$	21°	247°
Methyl Undecyl Ketone from Lauric Acid	$CH_3.CO.C_{11}H_{23}$	28°	263°
Methyl Dodecyl Ketone	$CH_3.CO.C_{12}H_{25}$	34°	(207°)
Methyl Tridecyl Ketone from Myristic Acid	$CH_3.CO.C_{13}H_{27}$	39°	(224°)
Methyl Tetradecyl Ketone	$CH_3.CO.C_{14}H_{29}$	43°	(231°)
Methyl Pentadecyl Ketone from Palmitic Acid	$CH_3.CO.C_{15}H_{31}$	48°	(244°)
Methyl Hexadecyl Ketone from Margaric Acid	$CH_3.CO.C_{16}H_{33}$	52°	(252°)
Methyl Heptadecyl Ketone from Stearic Acid	$CH_3.CO.C_{17}H_{35}$	55°	(265°)

The boiling points, inclosed in parentheses, were determined under 100 mm. pressure.

Methyl Ethyl Ketone occurs in crude wood spirit. *Methyl* sec.-*Butyl Ketone* results from the interaction of methyl-acrylic ester, $CH_2{:}C(CH_3).CO_2R$, with two molecules of magnesium methyl iodide (C. 1907, I. 559). *Methyl Hexyl Ketone* is obtained from œnanthol and diazomethane (mode of formation 13, p. 218).

Pinacoline is obtained by the withdrawal of water from the pinacone, tetramethyl ethylene glycol, $(CH_3)_2C(OH).C(OH)(CH_3)_2$, and from trimethyl acetyl chloride and zinc methyl (p. 217). When oxidized with chromic acid, it breaks down into trimethyl acetic and formic acid. Potassium permanganate converts it into trimethyl pyroracemic acid (*q.v.*). It is converted by iodomethane and alkali into *Pentamethyl Acetone* $(CH_3)_3C.COCH(CH_3)_2$, b.p. 134° (A. **310**, 325). Reduction produces pinacolyl alcohol (p. 122). For further changes, see C. 1906, II. 496. *Homologous pinacones* yield homologous pinacolines; thus *Methyl Ethyl Pinacone*, $\genfrac{}{}{0pt}{}{CH_3}{C_2H_5}{>}C(OH).C(OH){<}\genfrac{}{}{0pt}{}{CH_3}{C_2H_5}$, yields *Ethyl tert.-Amyl Ketone*,

$$\genfrac{}{}{0pt}{}{(CH_3)_2}{C_2H_5}{>}C.CO.C_2H_5$$

, b.p. 150°.

Methyl Nonyl Ketone is the chief constituent of oil of rue (from *Ruta graveolens*), from which it may be extracted by shaking with concentrated sodium bisulphite solution (C. 1902, I. 744). *Methyl Heptyl Ketone* occurs in the same oil (C. 1901, I. 1006; 1903, I. 29; B. **35**, 3587).

Acetone Peroxide. Two cyclic acetone peroxides are known. *Cyclo-diacetone Peroxide* $(CH_3)_2C{<}\genfrac{}{}{0pt}{}{O{-}O}{O{-}O}{>}C(CH_3)_2$, m.p. 132°, is prepared by the action of H_2SO_5 (Caro's acid) on acetone (B. **33**, 858). *Cyclo-triacetone Peroxide* $(C_3H_6O_2)_3$, m.p. 97°, is obtained from acetone and hydrogen peroxide, with special ease when in the presence of hydrochloric acid. It is insoluble in water, but soluble in benzene and in ether. It forms beautiful crystals, and explodes when struck or suddenly heated (B. **28**, 2265). Methyl ethyl ketone and H_2SO_5 produce *Methyl Ethyl Ketone Peroxide* $(C_4H_8O_2)_2$, a colourless oil, which explodes above 100° (C. 1907, I. 944).

I. HALOGEN SUBSTITUTION PRODUCTS OF THE KETONES, PARTICULARLY ACETONE

Monochloracetone, $CH_3.CO.CH_2Cl$, b.p. 119°, is obtained when chlorine is conducted into cold acetone (A. **279**, 313), preferably in the presence of marble (B. **26**, 597); also by the electrolysis of a mixture of acetone and hydrochloric acid (C. 1902, I. 101). Its vapours provoke tears.

a-Dichloracetone, $CH_3.CO.CHCl_2$, b.p. 120°, is formed on treating warmed acetone with chlorine, and is also obtained from dichloraceto-acetic ester (B. **15**, 1165). **β-Dichloracetone**, $ClCH_2.CO.CH_2Cl$, m.p. 45°, b.p. 172–174°, is obtained by the chlorination of acetone and in the oxidation of *a-dichlorhydrin*, $CH_2Cl.CH(OH).CH_2Cl$ (*q.v.*), with potassium dichromate and sulphuric acid.

sym.-**Tetrachloracetone**, $CHCl_2.CO.CHCl_2+2H_2O$, m.p. 48–49°, is obtained by the action of potassium chlorate and hydrochloric acid on chloranilic acid (B. **21**, 318) and triamidophenol (B. **22**, R. 666); or of chlorine on phloroglucinol (B. **22**, 1478). unsym.-*Tetrachloracetone*, $CH_2Cl.CO.CCl_2$, b.p. 183°, is produced by the action of chlorine on isopropyl alcohol (C. 1897, I. 28). *Pentachloracetone*, $CHCl_2.CO.CCl_3$, b.p. 193°, is obtained from chlorine and acetone (A. **279**, 317).

Monobromacetone, $CH_2Br.CO.CH_3$, b.p.$_8$ 31° (B. **29**, 1555; **31**, 2684). *Pentabromacetone*, m.p. 74°, is produced from acetone dicarboxylic acid and bromine (C. 1899, I. 596). *Perbromacetone*, $CBr_3.CO.CBr_3$, m.p. 110–111°, is obtained from triamidophenol (B. **10**, 1147), and bromanilic acid (B. **20**, 2040; **21**, 2441) by means of bromine and water.

Iodoacetone, $CH_3.CO.CH_2I$, b.p.$_{11}$ 58°, is produced when potassium iodide in an aqueous methyl alcohol solution acts on monochloracetone (B. **29**, 1557). It is a heavy oil with an intolerable pungent odour.

β-Di-iodoacetone, $CH_2I.CO.CH_2I$, results when iodine chloride acts on acetone.

β-Chlorisobutyl Methyl Ketone, $(CH_3)_2.CCl.CH_2.CO.CH_3$, and *Di-β-chlorisobutyl Ketone,* $(CH_3)_2CCl.CH_2.CO.CH_2CCl(CH_3)_2$, are the readily decomposable addition products of *mesityl oxide* and *phorone* with hydrochloric acid. *ω-Bromobutyl Methyl Ketone,* see Acetobutyl Alcohol.

γ-Dibromoketones are prepared from the *oxetones* (*q.v.*) by the addition of 2HBr, *e.g.* *γ-Dibromobutyl Ketone,* $(CH_3CHBr.CH_2.CH_2)_2CO$, is formed from dimethyl oxetone and 2HBr, or by the addition of 2HBr to diallyl acetone (p. 232) *a-Dichloroketones* are discussed with the diketones.

2. ALKYL ETHERS OF THE ORTHO-KETONES

The ketones may be regarded as the anhydrides of hypothetical glycols, which bear the same relation to the ketones that the orthocarboxylic acids do to the carboxylic acids. In this sense it is then permissible to speak of ortho-ketones. Their alkyl ethers, corresponding with the acetals, are produced by heating the β-diethoxy-carboxylic acids, and also from acetone by means of orthoformic ester (*Claisen,* B. **31,** 1010):

$$CH_3.C(OC_2H_5)_2CH_2.CO_2H \longrightarrow CH_3.C(OC_2H_5)_2.CH_3+CO_2$$
$$CH_3.CO.CH_3+HC(OC_2H_5)_3 \longrightarrow CH_3.C(OC_2H_5)_2CH_3+HCO_2C_2H_5.$$

Orthoacetone Methyl Ether, $(CH_3)_2C(OCH_3)_2$, b.p. 83°. *Orthoacetone Ethyl Ether,* b.p. 114°, is a liquid with an odour resembling that of camphor. These substances are stable when pure, but water or a trace of mineral acid causes them to break down into ketones and alcohols.

The ortho-ester homologues of orthoformic esters react on ketones like the first member, and the same may be said of the imido-ether hydrochloride and alcohol mixture. *Methyl Ethyl Ketone Orthoethyl Ether,* b.p. 120°; *Diethyl Ketone Orthoethyl Ether,* b.p. 154°; *Dipropyl Ketone Orthoethyl Ether,* b.p.$_{12}$ 70°, are prepared from acetimido-ether hydrochloride or phenyl acetimido-ether hydrochloride and alcohol (B. **40,** 3020).

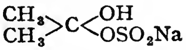
3. KETONE HALIDES

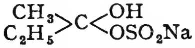
are produced, as mentioned on p. 220, by the action of PCl_5, PCl_3Br_2, and PBr_5 upon ketones. They easily give up the halogen in form of acid, forming *halogen olefines* (p. 96), which in turn yield acetylene, by the action of alkalis (p. 96).

Acetone Chloride, *Chloracetol,* $CH_3.CCl_2.CH_3$, b.p. 70°; $D_{16}=1·827$. *Bromacetol,* b.p. 114°; $D_0=1·8149$. *Methyl Ethyl Dichloromethane,* $CH_3.CCl_2.C_2H_5$, b.p. 96°. *Methyl Ethyl Dibromomethane,* b.p. 144°. *Methyl tert.-Butyl Dichloromethane,* $CH_3.CCl_2.C(CH_3)_3$, is produced from pinacoline by PCl_5 (comp. C. 1906, II. 496). *Heptachloropropane,* $CHCl_2.CCl_2.CCl_3$, m.p. 30°, b.p. 150°, is obtained from pentachloracetone (A. **297,** 314).

4. KETONE BISULPHITES AND SULPHOXYLATES

The addition compounds, which many ketones form with alkali bisulphites, comparably with the aldehydes (p. 207), are probably salts of acid sulphurous esters with ortho-ketones:

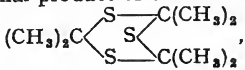

$\begin{matrix}CH_3\\CH_3\end{matrix}\!>C<\!\begin{matrix}OH\\OSO_2Na\end{matrix}$


$\begin{matrix}CH_3\\C_2H_5\end{matrix}\!>C<\!\begin{matrix}OH\\OSO_2Na\end{matrix}$

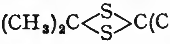
With alkali cyanides they yield hydroxy-acid nitriles (C. 1903, I. 1244). Reduction produces *ketone sulphoxylates,* $(CH_3)_2C(OH).OSONa$, which are also formed, together with bisulphites, from ketones and hydrosulphites (C. 1907, I. 855).

5. SULPHUR DERIVATIVES OF THE SATURATED KETONES

A. **Thioketones and their Sulphones.**—When hydrogen sulphide acts on a cold mixture of acetone and concentrated hydrochloric acid, the first product is a volatile body with an exceedingly disagreeable odour which spreads with great rapidity. It is probably thioacetone, which has not been further investigated. The final product of the reaction is—

Trithioacetone,  $(CH_3)_2C\begin{matrix}S\text{—}C(CH_3)_2\\ S\\ S\text{—}C(CH_3)_2\end{matrix}$, m.p. 24°, b.p.$_{18}$ 130°. Potassium permanganate oxidizes it to—

Trisulphone Acetone, $[(CH_3)_2CSO_2]_3$, m.p. 302°. When distilled at the ordinary pressure it is converted into

Dithioacetone,  $(CH_3)_2C{<}\begin{matrix}S\\S\end{matrix}{>}C(CH_3)_2$, b.p. 183–185°. This is also formed in the action of phosphorus trisulphide on acetone. It is converted, by oxidation, into—

Disulphone Acetone, $[(CH_3)_2CSO_2]_2$, m.p. 220–225°.

Methyl ethyl ketone behaves similarly (C. 1903, II. 281).

B. **Mercaptols and their Sulphones.**—Although the ketone derivatives corresponding with the *acetals* cannot be derived from ketones and alcohols by the withdrawal of water, it is possible to obtain the *mercaptols*—the ketone derivatives corresponding with the *mercaptals*—in this manner; but best, however, by the action of hydrochloric acid on ketones and mercaptans:

$$(CH_3)_2CO+2C_2H_5SH \xrightarrow{HCl} (CH_3)_2C(SC_2H_5)_2+H_2O.$$

Like the mercaptals, they are liquids with unpleasant odour.

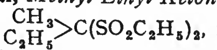
Acetone Ethyl Mercaptol, *Dithioethyl Dimethyl Methane,* $(CH_3)_2C(SC_2H_5)_2$, b.p. 190–191°, may be prepared from mercaptan. However, to avoid the intolerable odour of the latter, sodium ethyl thiosulphate and hydrochloric acid are used (p. 147). It combines with methyl iodide (B. **19,** 1787; **22,** 2592). By this means, from a series of simple and mixed ketones, corresponding mercaptols have been made, and in nearly all instances they have been oxidized to the corresponding sulphones, some of which possess medicinal value.

Sulphonal, *Acetone Diethyl Sulphone,* $(CH_3)_2C(SO_2C_2H_5)_2$, m.p. 126°, was discovered by *Baumann,* and was introduced into medicine, as a very active sleep-producing agent, by *Kast* in 1888. It is prepared by oxidation of acetone mercaptol with potassium permanganate:

$$(CH_3)_2.C(SC_2H_5)_2 \xrightarrow{4O} (CH_3)_2.C(SO_2C_2H_5)_2.$$

Sodium hydroxide and methyl iodide (A. **253,** 147) acting on *ethylidene diethyl sulphone* (p. 210) produce it:

$$CH_3CH(SO_2C_2H_5)_2 \xrightarrow{NaOH} CH_3.CNa(SO_2C_2H_5)_2 \xrightarrow{CH_3I} (CH_3)_2C(SO_2C_2H_5)_2.$$

Trional, *Methyl Ethyl Ketone Diethyl Sulphone, Diethyl Sulphone Methyl Ethyl Methane,*  $\begin{matrix}CH_3\\C_2H_5\end{matrix}{>}C(SO_2C_2H_5)_2$, m.p. 75°; **Tetronal,** *Pentane-γγ-diethyl Sulphone,* $(C_2H_5)_2C(SO_2C_2H_5)_2$, m.p. 85°; **Pentane-γγ-dimethyl Sulphone,** $(C_2H_5)_2C(SO_2CH_3)_2$, m.p. 132–133°, and other "*sulphonals,*" are prepared similarly to *sulphonal,* and act in like manner. However, *Acetone Dimethyl Sulphone,* $(CH_3)_2C(SO_2CH_3)_2$, not containing an ethyl group, no longer acts like sulphonal.

6. NITROGEN DERIVATIVES OF THE KETONES

A. **Nitro-compounds.**—*Pseudonitroles* (p. 153) and *Mesodinitroparaffins* (p. 154) have already been discussed after the mononitroparaffins.

B. **Ammonia** and ketones.—Two bases result from the action of ammonia on acetone: **diacetonamine** and **triacetonamine** (p. 230). From methylethyl ketone, diethyl ketone, and methyl propyl ketone, ammonia produces oils of the formula $R_2C(N{:}CR_2)_2$, from which the original ketone is easily recovered (C. 1905, II. 540; 1907, I. 810).

C. Hydroxylamine and ketones.

Ketoximes (*V. Meyer*).—In general, the ketoximes are formed with greater difficulty than the aldoximes (B. **39**, 1452). It is usually best to apply the hydroxylamine in a strongly alkaline solution (B. **22**, 605; A. **241**, 187). They are also produced when the pseudonitroles are reduced by free hydroxylamine or potassium hydrosulphide (B. **28**, 1367; **29**, 87, 98). They are very similar in properties to the aldoximes. Acids resolve them into their components, whilst sodium amalgam and acetic acid convert them into *primary amines* (p. 158). They are characteristically distinguished from the aldoximes by their behaviour towards acid chlorides or acetic anhydride, yielding in part acid esters; and by their conversion by the same reagents, as well as by HCl or H_2SO_4 in glacial acetic acid, into acid amides (*Beckmann's inversion*, B. **20**, 506, 2580; comp. also B. **24**, 4018; A. **312**, 172, note).

$$\begin{matrix}CH_3\\ CH_3CH_2CH_2\end{matrix}\!\!>\!C{=}NOH \longrightarrow CH_3CO.NHCH_2CH.CH_3.$$

Methyl Propyl Ketoxime. Acetopropylamide.

If the two alkyl groups in a ketone differ only slightly from one another, two isomeric amides are formed. If one alkyl group contains many more carbon atoms than the other, it is usually the group richer in carbon that wanders to the nitrogen atom (C. 1904, I. 355). For the investigation of this change, which is comparable to that undergone by carboxylic bromamides, azides, and hydroxamic acids (p. 244), see C. 1903, I. 489.

Nitrogen tetroxide converts the ketoximes into *pseudonitroles* (p. 153). Chlorine and sodium hydroxide or bromine and pyridine produce 1,1-chloro- and bromo-nitrosoparaffins (p. 153).

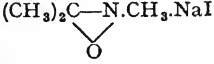
Ketoximes combine with hydrocyanic acid to form nitriles of α-amidoxyl carboxylic acids (B. **29**, 62).

Acetoxime, $(CH_3)_2C:NOH$, m.p. 59–60°, b.p. 135°, smells like chloral. It dissolves readily in water, alcohol, and ether, from which it crystallizes well (B. **20**, 1505; **39**, 876).

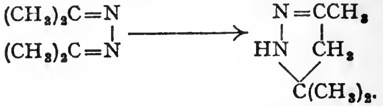
The hydroxyl hydrogen present in acetoxime may be replaced by acid radicals through the agency of acid chlorides or anydrides (B. **24**, 3537).

Methyl Ethyl Ketoxime, b.p. 152–153°. *Methyl* n-*Propyl Ketoxime,* b.p. 168° (C. 1898, II. 474), is an oil with an agreeable odour. *Methyl Isopropyl Ketoxime,* b.p. 157°. *Methyl n-Butyl Ketoxime,* b.p. 185°. *Methyl tert.-Butyl Ketoxime, Pinacoline Oxime,* m.p. 75°, reacting with PCl_5 produces aceto-tert.-butylamine. Nitrogen tetroxide does not produce pseudonitroles, but a *nitrimine,* $C(CH_3)_3.C(CH_3):N.NO_2$, or the desmotrope $C(CH_3)_3C(:CH_2).N:NOOH$. (Comp. mesityl nitrimine, p. 231, and A. **338**, 1.) n-*Butyrone Oxime,* b.p. 193°. *Isobutyrone Oxime,* m.p. 6–8°, b.p. 181–185°. *Methyl Nonyl Ketoxime,* m.p. 42°, behaves contrary to the rule (see above) and undergoes internal change under the influence of concentrated sulphuric acid, forming considerable quantities of capric methylamide, $C_9H_{19}CONHCH_3$, together with acetononylamine (B. **35**, 3592). *Capryl Ketoxime,* m.p. 20°. *Nonyl Ketoxime,* m.p. 12°. *Lauryl Ketoxime,* $(C_{11}H_{23})_2C:N.OH$, m.p. 39° *Myristyl Ketoxime,* $(C_{13}H_{27}C:N.OH$, m.p. 51°. *Palmityl Ketoxime,* $(C_{15}H_{12})_2C:N.OH$, m.p. 59°. *Stearyl Ketoxime,* $(C_{17}H_{35})_2C:N.OH$, m.p. 62°.

When a solution of a ketoxime is acted on by iodo-alkyls in the presence of sodium methoxide, a mixture is formed, which on distillation yields alkylated oximes, such as $(CH_3)_2C:NOCH_3$. These pass over, and alkylated isoketoximes remain behind combined with NaI as  $(CH_3)_2\underbrace{C\text{—}N}_{O}CH_3.NaI$. The alkyl isoketoxime cannot be obtained from this compound.

Acetoxime Ethyl Ether, $(CH_3)_2C{=}NOCH_3$, b.p. 72°. *Methyl Isoacetoxime Sodium Iodide,*  $(CH_3)_2\underbrace{C\text{—}N}_{O}.CH_3.NaI$, m.p. 206°, with decomposition, and others of this group, see C. 1901, II. 184.

D. **Ketazines** (*Curtius* and *Thun*).—An excess of hydrazine acting on the ketones produces the unstable, secondary symmetric hydrazines, readily changing even in the cold into ketazines, which are quite stable towards alkalis (B. **25**, R. 80). Dimethyl ketazine in contact with maleïc acid changes into the isomeric trimethyl pyrazoline (B. **27**, 770; C. 1901, II. 1121):



The homologues of methyl-alkyl ketazine behave similarly, whilst diethyl ketazine does not undergo the change (C. 1898, II. 1249).

Bis-dimethyl Azimethylene, *Dimethyl Ketazine,* $[(CH_3)_2C{:}N]_2$, b.p. 131°; *Bis-methyl Ethyl Azimeththylene,* b.p. 170°; *Bis-methyl Propyl Azimethylene,* b.p. 197°; *Bis-methyl Hexyl Azimethylene,* b.p. 290°; *Bis-diethyl Azimethylene,* b.p. 193°.

E. **Ketone Phenylhydrazones** (*E. Fischer,* B. **16**, 661; **17**, 576; **20**, 513; **21**, 984).—These compounds result by the action of phenylhydrazine on the ketones. The phenylhydrazine is added to the ketone until a sample of the mixture no longer reduces an alkaline copper solution. They behave like the aldehyde phenylhydrazones (p. 213).

Acetone Phenylhydrazone, $(CH_3)_2C{:}N_2HC_6H_5$, m.p. 16°, b.p.$_{93}$ 165°.

Methyl n-Propyl Ketone Phenylhydrazone, b.p.$_{100}$ 206°.

p-Nitrophenylhydrazones are specially suitable for identifying ketones on account of the relative insolubility of the compound formed. *Acetone* p-*Nitrophenylhydrazone,* $(CH_3)_2C{:}NNHC_6H_4NO_2$, m.p. 148° (C. 1904, I. 14).

Ketone Semicarbazones result when ketones are mixed with semicarbazide, $NH_2CO.NH.NH_2$ (*q.v.*) at ordinary temperatures. Such compounds are particularly suitable for the identification of the ketones, on account of the excellent way they crystallize. *Acetone Semicarbazone,* $(CH_3)_2C{:}NNHCONH_2$, m.p. 187°. *Ethyl Methyl Ketone Semicarbazone,* m.p. 135°. *Diethyl Ketone Semicarbazone,* m.p. 139°, and other members, see B. **34**, 2123.

3B. Olefine and Diolefine Ketones.

Olefine ketones, in which the double bond is situated next to the keto-group, are very easily prepared, and are interesting in their behaviour.

(1) (*a*) $\alpha\beta$-olefine ketones are obtained from the product of condensation of ketones with aldehydes or ketones; the 1,3-keto-alcohols which are formed easily give up water:

$$CH_3CHO+CH_3COCH_3 \longrightarrow CH_3CH(OH)CH_2COCH_3 \longrightarrow CH_3CH{:}CHCOCH_3.$$

Condensation of several molecules of the same ketone results in the formation of $\alpha\beta$-olefine ketones and $\alpha_2\beta_2$-diolefine ketones: acetone yields *Mesityl Oxide* and *Phorone*:

$$2CH_3COCH_3 \longrightarrow (CH_3)_2C{:}CHCOCH_3 \xrightarrow{(CH_3)_2CO} (CH_3)_2C{:}CHCOCH_3C(CH_3)_2.$$

(*b*) The haloid esters of the 1,3-keto-alcohols, such as β-chloro- and β-bromoketones, easily give up halogen acids, forming $\alpha\beta$-olefine ketones; *e.g.* β-chloroketones (prepared from β-chloropropionyl chloride and zinc alkyls: mode of formation, p. 217), and diethyl aniline yield vinyl alkyl ketones (C. 1906, I. 650):

$$ClCH_2CH_2COCl \xrightarrow{Zn(C_2H_5)_2} ClCH_2CH_2COC_2H_5 \longrightarrow CH_2{:}CHCOC_2H_5.$$

(*c*) Allyl alkyl ketones, which can be prepared from the acid nitriles, allyl iodide and zinc (comp. mode of formation 9, p. 217) very easily change into propenyl alkyl ketones, under the influence of mineral acids (C. 1905, I. 431):

$$CH_3C{:}N \xrightarrow{C_3H_5ZnI} CH_3COCH_2CH{:}CH_2 \longrightarrow CH_3COCH{:}CHCH_3.$$

(2) Olefines with any desired position of the double bond can be obtained

by decomposing olefine-substituted β-ketone acid esters or β-diketones (comp. mode of formation 13, p. 218); *e.g.* allyl acetic ester gives allyl acetone; dimethyl allyl acetyl acetone yields dimethyl heptenone.

The αβ-olefine ketones are remarkable for the great additive capacity of their C=C group, which approximates to that of the C=O group. Hydroxylamine produces not only oximes but also *β-Hydroxylamino-oximes*, RCH(NHOH).CH_2C(:NOH)R. Ammonia, primary and secondary amines are particularly easily taken up, forming *β-aminoketones.* Hydrazines react with the CO and C=C groups, producing cyclic *pyrazolines.* Mercaptans form not only mercaptols, but also mercapto-mercaptols, even when the C=C group is not contiguous to the CO group; *e.g.*

$$CH_3CH(SC_2H_5)CH_2C(SC_2H_5)_2CH_3, \quad CH_3CH(SC_2H_5)CH_2CH_2C(SC_2H_5)_2CH_3,$$

etc. In phorone, *only* the two C=C groups react:

$$(CH_3)_2C(SC_2H_5).CH_2.CO.CH_2C(SC_2H_5)(CH_3)_2$$ (B. **37**, 502).

Sulphurous and hydrocyanic acids sometimes unite with the C=C group rather than with the CO. Malonic ester, acetoacetic ester, and other such reactive bodies similarly unite with the C=C bond of αβ-olefine ketones, forming $RCOCH_2CR.CH(CO_2C_2H_5)_2$, etc.

Addition compounds with the halogen acids are very readily formed.

It is a general rule that, when HX becomes attached to these unsaturated substances, *the hydrogen atom always takes the α- position to the* CO *group, and the* X *group the β-position.*

Bromine forms αβ-dibromoparaffins, which readily give up HBr, leaving *α-bromo-olefine ketones,* which yield α-diketones on hydrolysis (B. **34**, 2092).

Vinyl Ethyl, Vinyl Propyl, Vinyl Isopropyl Ketone, CH_2:CHCOR, b.p.$_{47}$ 31°, b.p.$_{10}$ 24°, and b.p.$_{10}$ 32°, are produced from β-chloropropyl ethyl ketone, β-chloropropyl propyl ketone, and β-chloropropyl isobutyl ketone. They all easily undergo polymerization.

Allyl Methyl Ketone, b.p. 108°, *Allyl Ethyl Ketone,* b.p. 127°, and *Allyl Propyl Ketone,* b.p. 147°, CH_2:CH.CH_2COR, are readily changed by mineral acids into *Propenyl Methyl Ketone,* b.p. 121°, *Propenyl Ethyl Ketone,* b.p. 137°, and *Propenyl Propyl Ketone,* b.p. 157°.

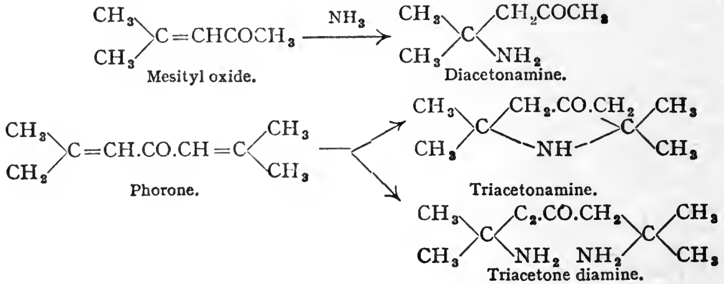
Ethylidene Acetone, $CH_3CH=CH.CO.CH_3$, b.p. 122°. It has a penetrating odour like that of crotonaldehyde. It is formed when *hydracetyl acetone* (*q.v.*) is boiled with acetic anhydride or anhydrous oxalic acid (B. **25**, 3166; **34**, 2092). *Isobutylidene Acetone,* $(CH_3)_2CH.CH$:CH.$COCH_3$, b.p.$_{16}$ 51° (C. 1900, I. 403). *Isoamylidene Acetone* $(CH_3)_2CH.CH_2CH$:$CHCOCH_3$, b.p. 180° (B. **27**, R. 121; C. 1897, I. 365). *Heptachlorethylidene Acetone,* $CHCl_2CCl=CCl.CO.CCl_3$, b.p.$_{14}$ 184°, results when *trichloracetyl tetrachlorocrotonic acid* is heated with water (B. **25**, 2695).

Mesityl Oxide, $(CH_3)_2C=CH.CO.CH_3$, b.p. 130°, is a liquid smelling like peppermint. **Phorone,** $(CH_3)_2C=CH.CO.CH=C(CH_3)_2$, m.p. 28°, b.p. 196°. These are formed simultaneously on treating acetone with dehydrating agents, *e.g.* $ZnCl_2$, H_2SO_4, and HCl. Hydrochloric acid is best adapted for this purpose, the acetone being saturated with it, while it is cooled. The addition products which are first formed, $(CH_3)_2CCl.CH_2.COCH_3$ and $(CH_3)_2CCl.CH_2.CO.CH_2.CCl(CH_3)_2$, are decomposed by alkali hydroxides, and the mesityl oxide and phorone then separated by distillation. When acetone is condensed by lime or sodium ethylate there is produced along with the mesityl oxide a cyclic ketone isomeric with phorone, called **isophorone** (Vol. II.). **Camphorphorone** is also isomeric with these two phorones. Mesityl oxide is also produced when *diacetone alcohol* (*q.v.*) and *diacetonamine* (p. 230) are heated alone; also, together with acetone, when phorone is heated with dilute sulphuric acid, which eventually causes it to break down into *two* molecules of acetone, as the result of water absorption (A. **180**, 1); also by the action of isobutylene on acetic anhydride in the presence of a little $ZnCl_2$ (B. **27**, R. 942). Mesityl oxide combines with ammonia to form diacetonamine (p. 230) and with hydrazine to trimethyl pyrazoline (Vol. II.). Mesityl oxide takes up two and phorone four bromine atoms. Just as acetone condenses to mesityl oxide and phorone, so the homologous ketones, and methyl ethyl ketone, methyl propyl ketone, methyl heptyl ketone, and methyl nonyl ketone are condensed by hydrochloric acid (B. **36**, 2555) or zinc chloride, and acetyl chloride (C. 1903, II. 566) to *homologues of mesityl oxide and phorone.*

Historical.—*Kane* discovered mesityl oxide in 1838, when he obtained it, together with mesitylene, by the action of concentrated sulphuric acid on acetone. At that time he regarded acetone as alcohol, and called it *mesitalcohol.* In mesityl oxide and mesitylene, *Kane* thought he had discovered bodies which bore the same relation to mesityl alcohol or acetone that ethyl ether or ethyl oxide and ethylene bear to ethyl alcohol. *Kekulé* developed the formula $(CH_3)_2.C{=}CH.CO.CH_3$ for mesityl oxide, which was substantiated later by *Claisen.* *Baeyer* discovered phorone, and *Claisen* assigned to it the formula $(CH_3)_2C{=}CH.CO.CH{=}C(CH_3)_2$ (A. **180,** 1).

THE ACTION OF AMMONIA ON MESITYL OXIDE AND PHORONE

Ammonia unites with these bodies at their double bonds and forms three bases, *Diacetonamine. Triacetonamine,* and *Triacetone Diamine*—the same that are formed from ammonia and acetone (*Heintz,* A. **174** 133; **198,** 42; **203,** 336). There are two possible courses that the reaction may follow: firstly, that the acetone is condensed to mesityl oxide and phorone by the ammonia which then become converted into the amines, or secondly, the ammonia forms a simple addition compound, $(CH_3)_2C{<}^{OH}_{NH_2}$, which then condenses.



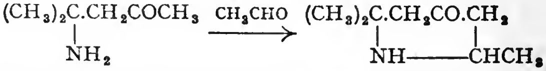
(A. **203,** 336.)

Diacetonamine forms a colourless liquid, slightly soluble in water, which is decomposed into mesityl oxide and ammonia by distillation (B. **7,** 1387). It shows a strongly alkaline reaction and forms crystalline salts with one equivalent of acid. The *hydrochloride,* acted on by potassium nitrite, yields *Diacetone Alcohol,* $(CH_3)_2C(OH)CH_2COCH_3$ (*q.v.*), which can be considered to be a derivative of diacetonamine. It loses water and changes to mesityl oxide. Urea derivative of diacetonamine, see B. **27,** 377. *Diacetonamine Oxime,* m.p. 55°, b.p.$_{12}$ 121° (B. **34,** 300, 792).

Oxidation by chromic acid mixture produces amino-isobutyric acid, $(CH_3)_2C(NH_2)COOH$ (propalanine), and amino-isovaleric acid, $(CH_3)_2C(NH_2).CH_2COOH$.

Triacetonamine, m.p. 39·6°; NH_2O, m.p. 58°, is prepared from phorone and ammonia, and is an imide base (p. 165). It crystallizes anhydrous in needles, and with one molecule of water in large quadratic tables. It is weakly alkaline. Its hydrochloride with potassium nitrite yields a *nitrosamine* compound, $C_9H_{16}ON.NO$, m.p. 73°, which regenerates phorone when boiled with sodium hydroxide. The nitroso-body is transformed by hydrochloric acid back into triacetonamine. This substance, with bromine, forms N-*Bromotriacetonamine,* $C_9H_{16}ONBr$, m.p. 44° (B. **31,** 668). For further reactions, see Vol. II.

Phorone and primary amines produce n-*Methyl Triacetonamine,* etc. (B. **28,** R. 166). Just as the reaction of diacetonamine with acetone yields triacetonamine, so acetaldehyde produces *Vinyl Diacetonamine* (B. **17,** 1788).



$$\begin{array}{l}(CH_3)_2C.CH_2COCH_3\\ \quad |\\ \quad NH_2\end{array} \xrightarrow{CH_3CHO} \begin{array}{l}(CH_3)_2C.CH_2CO.CH_2\\ \quad |\qquad\qquad\quad |\\ \quad NH——CHCH_3\end{array}$$

With cyanacetic ester an analogous δ-*lactam* is formed (B. **26,** R. 450).

ACTION OF HYDROXYLAMINE ON MESITYL OXIDE AND PHORONE

According to the conditions of experiment, hydroxylamine becomes added on to the mesityl oxide molecule and gives *Diacetone Hydroxylamine*, or else oxime formation takes place. In the case of phorone, however, only addition compounds are formed—*Triacetone Hydroxylamine* and *Triacetone Dihydroxylamine*, corresponding with the two compounds obtained with ammonia.

Mesityl Oxide Oxime, $\mathrm{(CH_3)_2C{=}CH.C(NOH)CH_3}$, α-form, b.p.$_9$ 83°, β-form, m.p. 49°, b.p.$_9$ 92°, is prepared from mesityl oxide and free hydroxylamine. It is obtained in two modifications. The oily α-oxime is transformed into the solid β-form by the action of heat on the hydrochloride, or by repeated distillation under reduced pressure. This body, acted on by hydroxylamine hydrochloride and boiled with alkali, regenerates the α-modification.

Mesityl Nitrimine, $\mathrm{(CH_3)_2C{=}CH.C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{N.NO_2}}$, m.p. 155°, with rapid decomposition, is produced when both modifications of mesityl oxide oxime are treated with amyl nitrite in glacial acetic acid (B. **32**, 1336). Reduction changes it to *Trimethyl Pyrazoline* (Vol. II.). Heated with water it forms an isomeric *keto-trimethyl dihydro-isoxazole oxime* (Vol. II.); oxidation with nitric acid changes it to *Nitrilomesityl Dioxime Peroxide*. This is converted by aniline in glacial acetic acid solution into *Anilonitro-acetone*, which, in turn, is changed by sulphuric acid into nitro-acetone, (A. **319**, 230), a derivative of hydroxy-acetone:

Mesityl Oxide Semicarbazone, $\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_2{-}CO{-}CH_3}}{\mathrm{N{-}NH.CONH_2}}$, m.p. 162° (B. **33**, 1338).

Diacetone Hydroxylamine, $\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_2COCH_3}}{\mathrm{NHOH}}$, m.p. 52°, b.p.$_{10}$ 95°, is formed, together with α-mesityl oxide oxime, by the action of free hydroxylamine on mesityl oxide. Oxidation with chromic acid yields:

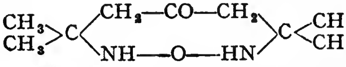
β-Nitroso-isopropyl Acetone, $\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_2{-}CO{-}CH_3}}{\mathrm{NO}}$, dimolecular form, m.p. 75°; monomolecular form, b.p.$_{11}$ 60°, which is also formed from diacetonamine (p. 230) by oxidation with persulphuric acid. In the *dimolecular* condition it forms white tabular crystals, which melt to a blue *monomolecular* liquid. It is easily decomposed (comp. nitrosoparaffins, p. 153, and B. **36**, 1069).

β-Nitro-isopropyl Acetone, $\mathrm{(CH_3)_2C(NO_2)CH_2COCH_3}$, b.p.$_{17}$ 119°, is produced when diacetone hydroxylamine is oxidized with nitric acid. It can be reduced back to its parent compound by aluminium amalgam (B. **36**, 158).

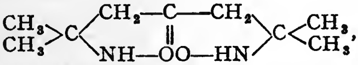
Triacetone Hydroxylamine, $\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_2{-}CO{-}CH_2}}{\mathrm{{-}{-}N(OH){-}{-}}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}$, m.p. 50°, is prepared from phorone and hydroxylamine hydrochloride, and yields with hydroxylamine, an *oxime*, m.p. 126°.

Triacetone Dihydroxylamine, $\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_2{-}CO{-}CH_2}}{\mathrm{NHOH\quad HOHN}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}$, m.p. 113°, b.p.$_{20}$ 135° (B. **36**, 657), results from interaction of phorone and two molecular proportions of free hydroxylamine. Reduced by Zn and HCl, it changes to triacetone diamine. Boiled with alkalis it gives:

Triacetone Dihydroxylamine Anhydride,



or



m.p. 111°. Reduction by Zn and HCl gives triacetone diamine (see above).

Dinitrosodiisopropyl Acetone, $\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_2{-}CO{-}CH_2}}{\mathrm{NO\qquad ON}}{>}\mathrm{C}{<}\genfrac{}{}{0pt}{}{\mathrm{CH_3}}{\mathrm{CH_3}}$, m.p. 132°, is produced from triacetone dihydroxylamine by chromic acid (B. **31**, 1379). On melting it forms a deep blue liquid.

The scheme on which this work is based requires that diacetonamine and diacetone hydroxylamine should be discussed as derivatives of diacetone alcohol with the ketoles; and triacetonamine, triacetone diamine, triacetone hydroxylamine, and triacetone dihydroxylamine, etc., as derivatives of the still unknown triacetone dialcohol among the ketodioles. They have, however, been examined before the olefine ketones, on account of their genetic connection with mesityl oxide and phorone.

Allyl Acetone, $CH_2{:}CH.CH_2.CH_2COCH_3$, is obtained from allyl acetoacetic ester. It is isomeric with mesityl oxide (C. 1898, II. 663; B. **33,** 1472).

Methyl Heptenone, $(CH_3)_2C{=}CH.CH_2.CH_2COCH_3$, b.p. 173°, is found in a number of ethereal oils which contain citral, linalool, and geraniol. It results from the distillation of cincolic anhydride (Vol. II.). Synthetically it can be produced by the action of sodium hydroxide solution on the reaction product of sodium acetyl acetone on amylene dibromide, $(CH_3)_2CBr.CH_2CH_2Br$ (B. **29,** R. 590). It is also prepared from dimethyl allyl acetoacetic ester, the result of the reaction between acetoacetic ester and amylene dibromide, and sodium ethoxide solution (B. **34,** 594). It possesses a penetrating odour like amyl acetate. Oxidation with $KMnO_4$ breaks it down to acetone and lævulinic acid; zinc chloride produces dihydro-m-xylol (A. **258,** 323; B. **28,** 2115, 2126).

Sorbic Ethyl Ketone, $CH_3.CH{:}CH.CH{:}CH.CO.C_2H_5$, b.p.$_{26}$ 93°, is prepared from sorbyl chloride and zinc ethyl (B. **34,** 2222).

Condensation of the respective $\alpha\beta$-olefine aldehydes (p. 214) with acetone leads to the formation of the following diolefine ketones (B. **28,** R. 608; C. 1906, II. 1112):

(1) *γ-Methyl Sorbic Methyl Ketone,* $CH_3CH{:}C(CH_3)CH{:}CHCOCH_2$, b.p.$_{12}$ 92°.

(2) *$\gamma\epsilon$-Dimethyl Sorbic Methyl Ketone,* $(CH_3)CH_2CH{:}C(CH_3)CH{:}CHCO.CH_3$, b.p.$_8$ 97°.

(3) *$\gamma\epsilon$-Diisopropyl Sorbic Methyl Ketone,* $(C_3H_7)CH_2CH{:}C(C_3H_7)CH{:}CHCOCH_3$.

Boiling with zinc chloride gives rise to benzene derivatives with varying facility: (1) no condensation; (2) a bad yield; (3) a better one (see Vol. II.).

Diallyl Acetone, $CH_2{=}CH.CH_2.CH_2COCH_2.CH_2.CH{=}CH_2$, b.p.$_{70}$ 116°, is prepared from diallyl acetone carboxylic ester (comp. Oxetone).

Pseudo-ionone is also a diolefine ketone, and is described in Vol. II., together with the olefine terpenes.

3c. Acetylene Ketones.

These are obtained by the action of acid chlorides on sodium compounds of alkyl acetylene.

Acetyl Œnanthylidene, $CH_3[CH_2]_4C{\equiv}C.COCH_3$, b.p.$_{18}$ 93°, is obtained from sodium œnanthylidene and acetyl chloride. It possesses an irritating odour. Dilute H_2SO_4 converts it into acetyl caproyl methane, $CH_3[CH_2]_4CO.CH_2COCH_3$ (C. 1900, II. 1231, 1262). Hydroxylamine and hydrazines combine with the acetylene ketones, forming *isoxazoles* and *pyrazoles* respectively (C. 1903, II. 122; 1904, I. 43).

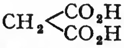
4. MONOBASIC CARBOXYLIC ACIDS

The organic acids are characterized by the atomic group, CO.OH, called *carboxyl,* of which the hydrogen can be replaced by metals and alcohol radicals, forming salts and esters. These organic acids may be compared to the sulphonic acids (p. 146), which contain the sulpho-group, $SO_2.OH$.

The number of carboxyl groups present in them determines their basicity, and distinguishes them as mono-, di-, tri-basic, etc., or as mono-, di-, and tri-carboxylic acids:

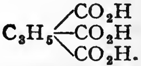
$CH_3.CO_2H$

Acetic Acid (Monobasic).



$CH_2{<}{CO_2H \atop CO_2H}$

Malonic Acid (Dibasic).



$C_3H_5\begin{cases}CO_2H\\CO_2H\\CO_2H.\end{cases}$

Tricarballylic Acid (Tribasic).

The monobasic *saturated* acids can be looked on as being combinations of the carboxyl group with alcohol radicals; they are ordinarily termed *fatty acids.* They correspond with the saturated primary alcohols and aldehydes. The *unsaturated* acids of the acrylic acid and propiolic acid series, corresponding with the unsaturated primary alcohols and aldehydes, are derived from the fatty acids by the loss of two and four hydrogen atoms.

They are distinguished as:

A. *Paraffin monocarboxylic Acids,* $C_nH_{2n}O_2$, formic acid or acetic acid series.

B. *Olefine monocarboxylic Acids,* $C_nH_{2n-2}O_2$, oleic or acrylic acid series.

C. *Acetylene monocarboxylic Acids,* $C_nH_{2n-4}O_2$, propiolic acid series.

D. *Diolefine carboxylic Acids,* $C_nH_{2n-4}O_2$.

Nomenclature.—The "Geneva nomenclature" deduces the names of the carboxylic acids, just like the alcohols (p. 102), the aldehydes (p. 193), and the ketones (p. 218), from the corresponding hydrocarbons; thus formic acid is [methane acid] and acetic acid is [ethane acid], etc.

The *radical* of the acid is the residue in combination with the hydroxyl group:

$CH_3.CO—$ Acetyl.
$CH_3.CH_2.CO—$ Propionyl.
$CH_3.CH_2.CH_2.CO—$ Butyryl.

The names of the trivalent hydrocarbon residues, which in the acid residues are united with oxygen, are indicated by the insertion of the syllable "en" into the names of the corresponding alcohol radicals:

$CH_3.C\equiv$ Ethenyl.
$CH_3.CH_2.C\equiv$ Ethylmethenyl.
$CH_3.CH_2.CH_2.\equiv$ n-Propylmethenyl.

The group $CH\equiv$, however, is not only called the methenyl group, but also the methine group.

Review of the Derivatives of the Monocarboxylic Acids.—Numerous classes of bodies can be derived by changes in the carboxyl group. In connection with the fatty acids mention will only be made of the *salts.* The other classes of derivatives will be considered as such after the fatty acids. They are:

(1) The *esters,* resulting from the replacement of hydrogen in the carboxyl group by alcohol radicals (p. 265).

(2) The *chlorides* (bromides, iodides, and fluorides), which are compounds of the acid radicals with the halogens (p. 269).

(3) The *acid anhydrides* (p. 271), compounds of the acid radicals with oxygen.

(4) The *acid peroxides* (p. 273).

(5) The *thio-acids* (p. 273), compounds of the acid radicals with SH.

(6) *The carbithionic acids.*

(7) The *acid amides* (p. 274), compounds of the acid radicals with NH_2.

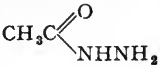
(8) The *acid nitriles* (p. 278).

Hence acetic acid yields the following:

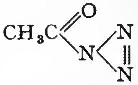
1. $CH_3.CO_2.C_2H_5$ Acetic Ethyl Ester.
2. $CH_3.COCl$ Acetyl Chloride.
3. $(CH_3.CO)_2O$ Acetic Anhydride.
4. $(CH_3.CO)_2O_2$ Acetyl Peroxide.
5. $CH_3.COSH$ Thioacetic Acid.
6. $CH_3.CSSH$ Methyl Carbithionic Acid.
7. $CH_3.CONH_2$ Acetamide.
8. $CH_3.C\equiv N$ Acetonitrile.

Besides the acid halides, amides, and nitriles, there exist the following more complex derivatives:—

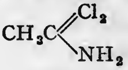
(9) *Hydrazides* (p. 278); (10) *azides* (p. 278); (11) *amide chlorides* (p. 281); (12) *imide chlorides* (p. 281); (13) *imido-ethers* (p. 281); (14) *thio-amides* (p. 282); (15) *thio-imido-ethers* (p. 282); (16) *hydroxamic acids* (p. 282); (17) *hydroxamoximes* (p. 283); (18) *nitrosolic acids* (p. 283); (19) *nitrolic acids* (p. 283); (20) *hydroxamyl chlorides* (p. 283); (21) *amidoximes* (p. 283); (22) *amidines* (p. 282); (23) *hydrazidines* (p. 284); (24) *formazyles*, and others:—

9.

$CH_3C\begin{array}{l}\diagup O\\ \diagdown NHNH_2\end{array}$

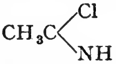
Acetohydrazide.

10.

$CH_3C\begin{array}{l}\diagup O\\ \diagdown N\begin{array}{l}\diagup N\\ \diagdown \| \\ \quad N\end{array}\end{array}$

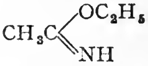
[Acetazide].

11.

$CH_3C\begin{array}{l}\diagup Cl_2\\ \diagdown NH_2\end{array}$

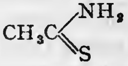
Acetamide Chloride.

12.

$CH_3C\begin{array}{l}\diagup Cl\\ \diagdown NH\end{array}$

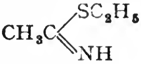
Acetimide Chloride.

13.

$CH_3C\begin{array}{l}\diagup OC_2H_5\\ \diagdown NH\end{array}$

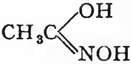
Acetimido-ether.

14.

$CH_3C\begin{array}{l}\diagup NH_2\\ \diagdown S\end{array}$

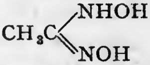
Thioacetamide.

15.

$CH_3C\begin{array}{l}\diagup SC_2H_5\\ \diagdown NH\end{array}$

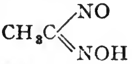
Thioacetimido Ether.

16.

$CH_3C\begin{array}{l}\diagup OH\\ \diagdown NOH\end{array}$

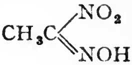
Acetohydroxamic Acid.

17.

$CH_3C\begin{array}{l}\diagup NHOH\\ \diagdown NOH\end{array}$

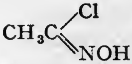
Acetohydroxamic Oxime.

18.

$CH_3C\begin{array}{l}\diagup NO\\ \diagdown NOH\end{array}$

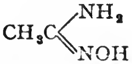
Acetonitrosolic Acid.

19.

$CH_3C\begin{array}{l}\diagup NO_2\\ \diagdown NOH\end{array}$

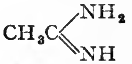
Ethyl Nitrolic Acid.

20.

$CH_3C\begin{array}{l}\diagup Cl\\ \diagdown NOH\end{array}$

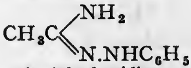
Acetohydroximic Acid Chloride.

21.

$CH_3C\begin{array}{l}\diagup NH_2\\ \diagdown NOH\end{array}$

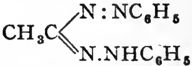
Acetamide Oxime.

22.

$CH_3C\begin{array}{l}\diagup NH_2\\ \diagdown NH\end{array}$

Acetamidine.

23.

$CH_3C\begin{array}{l}\diagup NH_2\\ \diagdown N.NHC_6H_5\end{array}$

Acetohydrazidine.

24.

$CH_3C\begin{array}{l}\diagup N:NC_6H_5\\ \diagdown N.NHC_6H_5\end{array}$ etc.

Methyl Formazyl.

Aromatic carboxylic acids, especially *benzoic acid*, are particularly suitable for the preparation of carboxylic acid derivatives, and various classes of substances which actually belong here, have been discovered and more closely studied in that series. Benzoic acid transmits its own facility in crystallization to its derivatives, so that the process of investigation becomes the easier.

Similarly, the *aromatic amines* and *hydrazines*, such as aniline, toluidine, and phenylhydrazine, are more easily prepared and more convenient to manipulate than the corresponding aliphatic compounds, so that in this direction also the benzene derivatives have been more closely investigated than the simple methane compounds.

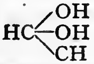
Numerous derivatives are also obtained by the replacement of the hydrogen atoms in the radical combined with hydroxyl by other atoms or groups. Only the *halogen substitution products* will be described under the fatty acids, after the discussion of the various classes mentioned in the preceding paragraphs.

The fatty acids can be recovered from all of the above classes of derivatives by simple reactions.

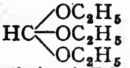
It has already been indicated under the oxygen derivatives of the methane hydrocarbons, that aldehydes, ketones, and carboxylic acids may be considered to be anhydrides of theoretical, non-existing diacid or triacid alcohols, in which the hydroxyl groups are attached to the same carbon atom (p. 99). The aldehydes and ketones were here especially referred to, because there were, among their acetals (p. 205) and the orthoketone alkyl ethers (p. 225), for example, stable ethers of glycols or orthoaldehydes and of orthoketones, ordinarily non-existent in the free state, among which chloral hydrate itself is included.

The trihydric alcohols, corresponding with the carboxylic acids, cannot exist, but ethers of them are known. The hypothetical, trihydric alcohols, of which the carbonic acids may be considered anhydrides, have been called *ortho acids*, comparably to tribasic phosphoric acid being termed *orthophosphoric acid* (A. **139,** 114; J. (1859) 152; B. **2,** 115). This designation has also been applied to the orthoaldehydes and orthoketones.

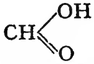
It is customary, therefore, to speak of "*hypothetical orthoformic acid*" and of "*orthoformic esters*" (the esters of tribasic formic acid), of *formic acid*—which, in reference to the relation of orthophosphoric to metaphosphoric acid, PO(OOH), might be termed *metaformic acid*—and of *formic acid esters :*



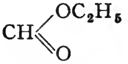
Orthoformic Acid.



Orthoformic Ethyl Ester.

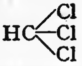


Formic Acid.

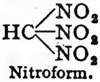


Formic Ethyl Ester.

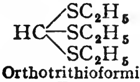
The *chloride, bromide,* and *iodide* corresponding with orthoformic acid are *chloroform, bromoform,* and *iodoform ;* further derivatives are *nitroform, orthotrithioformic ester, formyl trisulphonic acid,* and others :



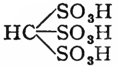
Chloroform.



Nitroform.



Orthotrithioformic Ester.



Formyl Trisulphonic Acid.

It is only in the case of formic acid that the *ortho-acid derivatives* require a special designation. They will be discussed immediately following the derivatives of the ordinary formic acid.

Comparably to the above, substances are known which are derived from orthoacetic acid, $CH_3C(OH)_3$:

$CH_3C(OC_2H_5)_3$	CH_3CCl_3	$CH_3C(NO_2)_3$	$CH_3C(NC_5H_{10})_3$
Orthoacetic Ethyl Ester.	**Methyl Chloroform.**	**Methyl Nitroform.**	**Orthoacetic Piperidide.**

A. MONOBASIC SATURATED ACIDS, PARAFFIN MONOCARBOXYLIC ACIDS, $C_nH_{2n+1}.CO_2H$

Formic acid, H.CO.OH, is the first member of this series. The radical HCO, which, here, is united to hydroxyl, is called *formyl.* This acid is distinguished from all its homologues and the unsaturated monocarboxylic acids, in that it exhibits not only the character of a monobasic acid, but also that of an aldehyde. To express in a name its aldehyde character the acid might be designated *hydroxyformaldehyde,*

$HO.C\begin{smallmatrix}\nearrow O\\ \searrow H\end{smallmatrix}.$

From a chemical standpoint, this acid is more closely connected with *glyoxylic acid,* $CHO.CO_2H$ (*q.v.*) than to acetic acid. Therefore, formic acid and its derivatives will be treated before acetic acid and its homologues are discussed.

FORMIC ACID AND ITS DERIVATIVES

It is not only the aldehyde character which distinguishes formic acid from acetic acid and its homologues, but it is also the absence of a chloride and anhydride, corresponding with acetyl chloride (*q.v.*) and acetic anhydride (*q.v.*). The withdrawal of water from formic acid leads to the formation of carbon monoxide, a reaction which does not take place in the case of any of the higher homologues.* Hydrocyanic acid, the nitrile of formic acid, has an acid nature, and therein differs from the indifferent nitriles of the homologous acids. Formic acid is twelve times stronger than acetic acid, as is shown by the affinity constants derived from the electric conductivity (*Ostwald*).

To the section on formic acid will be appended *carbon monoxide,* and its nitrogen-containing derivatives, the *isonitriles* or *carbylamines,* $C{=}N{-}R'$, and *fulminic acid,* $C{=}NOH$.

Formic Acid, $H.CO.OH$ [Methane Acid] (*Acidum formicum*), m.p. 8·6° (crystallizes at 0°), b.p.$_{100}$ 100 6°, $D_{20}=1{\cdot}22$, is found free in ants, in the procession caterpillar, *Bombyx processionea,* in pine needles, and in various animal secretions (perspiration), from all of which it may be obtained by distillation with water. It is almost certainly *not* present in stinging nettles [Tr.].

It is produced in the laboratory:

(1) By the oxidation of methyl alcohol and formaldehyde (B. **36,** 3304):

$$H.CH_2OH \xrightarrow{O} H.CHO \xrightarrow{O} H.CO_2H.$$

(2) By heating hydrocyanic acid, the nitrile of formic acid, with alkalis or acids:

$$HCN+2H_2O=HCOOH+NH_3.$$

(3) By boiling chloroform with alcoholic potassium hydroxide (*Dumas*):

$$CHCl_3+4KOH=HCOOK+3KCl+2H_2O.$$

(4) From chloral (*Liebig*), (5) from acetaldehyde disulphonic acid (see p. 208), and (6) from propargylic aldehyde (p. 215) and sodium hydroxide:

$$CCl_3.CHO+NaOH=HCCl_3+HCOONa;$$
$$(SO_3Na)_2CH.CHO+NaOH=(SO_3Na)_2CH_2+HCOONa;$$
$$CH{\equiv}C.CHO+NaOH=CH{\equiv}CH+HCOONa.$$

Remarkable and of technical importance is (7) the direct production of formates by the action of CO on concentrated potassium hydroxide at 100°, or more easily on soda-lime at 200–220° (*Berthelot,* A. **97,** 125; *Geuther,* A. **202,** 317; *Merz* and *Tibiriçá,* B. **13,** 718):

$$CO+NaOH=HCO.ONa.$$

(8) By action of acids on isocyanides or carbylamines (p. 247):

$$CN.C_2H_5+2H_2O=HCO_2H+C_2H_5NH_2.$$

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* Comp. *Dimethyl Ketene* (p. 290), *Di-Ketals* or *Carbon Suboxide* (Vol. I.), and *Di-Phenyl Ketene.*

(9) From fulminic acid by means of concentrated hydrochloric acid (see Formyl Chloridoxime, p. 244), hydroxylamine hydrochloride being formed simultaneously:

$$C{=}N.OH+2H_2O+HCl=H.CO_2H+NH_2OH.HCl.$$

(10*a*) By the reduction of moist carbon dioxide (carbonic acid) by potassium (*Kolbe* and *Schmitt*, A. **119**, 251):

$$3CO_2+4K+H_2O=2HCO.OK+K_2CO_3.$$

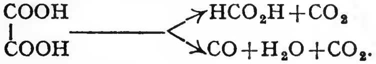
Formates are also produced by the action of sodium amalgam or electrolytic hydrogen (B. **38**, 4138) on ammonium carbonate and an aqueous solution of primary carbonates; likewise on boiling zinc carbonate with potassium hydroxide and zinc dust.

(10*b*) Potassium hydride combines at ordinary temperatures with CO_2, forming HCOOK. At higher temperatures (80°) there results a mixture of potassium formate and oxalate (C. 1905, II. 29). Potassium formate is also formed when CO and H_2 are passed together over heated potassium (*Moissan* C. 1902, I. 568):

$$2CO+KH=HCO_2K+C.$$

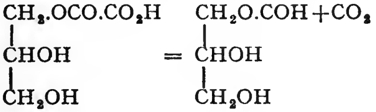
(11) Formic acid is best prepared from oxalic acid, by heating it with glycerol.

Oxalic acid heated alone decomposes into carbon dioxide and formic acid, or carbon monoxide and water, the latter decomposition preponderating:



$$\begin{array}{l}COOH\\ |\\ COOH\end{array} \longrightarrow \begin{cases}HCO_2H+CO_2\\ CO+H_2O+CO_2.\end{cases}$$

When, however, the acid is heated with glycerol in a distillation flask to 100–110°, glyceryl monoxalic ester is first formed, and afterwards by loss of carbonic acid, ***mono-formin***, the *monoformic ester* of *glycerol*:



$$\begin{array}{l}CH_2.OCO.CO_2H\\ |\\ CHOH\\ |\\ CH_2OH\end{array} = \begin{array}{l}CH_2O.COH+CO_2\\ |\\ CHOH\\ |\\ CH_2OH\end{array}$$

On further addition of crystallized oxalic acid the latter again breaks up into the anhydrous acid and water, which converts the glycerol formic ester into glycerol and formic acid:

$$C_3H_5O.CHO(OH)_2+H_2O=C_3H_5(OH)_3+CHO.OH.$$

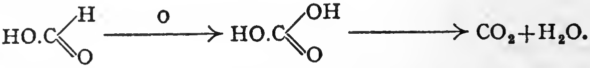
At first the acid is very dilute, but later it reaches 56 per cent. If anhydrous oxalic acid be employed at the beginning, a 95–98 per cent. formic acid is produced.

To obtain anhydrous formic acid, the aqueous product is boiled with lead oxide or lead carbonate. The lead formate is then decomposed, at 100°, by a current of hydrogen sulphide. Or, formic acid of high percentage may be dehydrated by means of boric anhydride (B_2O_3) (B. **14**, 1709); or, finally, sodium formate may be decomposed by sulphuric acid (C. 1905, I. 1701).

Formic acid is a mobile liquid which possesses a pungent odour and causes blisters on the skin. It mixes in all proportions with water, alcohol and ether, and yields the *hydrate* $4CH_2O_2+3H_2O$, b.p.$_{760}$ 107·1°, with dissociation into formic acid and water. Concentrated hot sulphuric acid decomposes formic acid into *carbon monoxide* and water.

A temperature of 160° suffices to break up the acid into carbon dioxide and hydrogen. The same change may occur at ordinary temperatures by the action of finely divided rhodium, iridium, and ruthenium, but less readily when platinum sponge is employed.

The aldehydic nature of formic acid explains its reducing property, its ability to precipitate silver from a hot neutral solution of silver nitrate, and mercury from mercuric nitrate, being itself oxidized to *carbon dioxide :*



$$HO.C\begin{matrix}H\\O\end{matrix} \xrightarrow{O} HO.C\begin{matrix}OH\\O\end{matrix} \longrightarrow CO_2+H_2O.$$

Formates, excepting the sparingly soluble lead and silver salts, are readily soluble in water. *Lead formate,* $(HCO_2)_2Pb$, crystallizes in beautiful needles and dissolves in 36 parts of cold water. *Silver formate,* HCO_2Ag, rapidly blackens on exposure to light.

Decomposition of Formates.—1. The alkali salts, heated to 250°, are converted into oxalates with evolution of hydrogen :

$$2HCO_2K=(CO_2K)_2+H_2.$$

2. Potassium formate, when heated with an excess of potassium hydroxide, decomposes with the formation of carbonate and the liberation of *pure hydrogen* (see Inorganic Chemistry) :

$$H.CO_2K+KOH=K_2CO_3+H_2.$$

3. The ammonium salt, heated to 230°, passes into *formamide :*

$$H.CO_2NH_4 \xrightarrow[230°]{-H_2O} H.CONH_2.$$

It may be distilled undecomposed under reduced pressure.

4. The silver salt and mercury salt, when heated, decompose into *metal,* carbon dioxide and formic acid (C. 1905, II. 304) :

$$2HCO_2Ag=2Ag+CO_2+H.CO_2H.$$

5. The *calcium* salt, when heated with the calcium salts of higher fatty acids, yields *aldehydes* (p. 190).

Monochloroformic acid, Cl.COOH, is regarded as chlorocarbonic acid. It will be discussed after carbonic acid.

Esters of Formic Acid are prepared (1) from formic acid, alcohol, and hydrochloric or sulphuric acid; (2) from sodium formate and hydrochloric or sulphuric acid; (3) from a mixture of formyl acetic anhydride, or acetyl formyl oxide, $HCOOCOCH_3$, and alcohols (C. 1900, II. 314); (4) from glycerol, oxalic acid, and alcohol. They are agreeably smelling liquids.

Formic Methyl Ester, m.p. −100°, b.p. 32·5° (B. **33**, 638).

Formic Ethyl Ester, b.p. 54·4°.

This *ester* serves in the manufacture of artificial rum and arrack, and for the union of the formyl group with organic radicals (see formyl acetone, etc.).

n-*Propyl Ester,* b.p. 81°. n-*Butyl Ester,* b.p. 107°. For higher esters consult A. **233**, 253; C. 1900, II. 314. The *allyl ester,* b.p. 90°.

Formamide, HCO.NH$_2$, b.p. 192–195°, with partial decomposition, b.p.$_{10}$ 90°, the *amide of formic acid* (comp. Acid Amides) is obtained (1) by heating ammonium formate (see above) to 230° (B. **12**, 973;

15, 980), or (2) ethyl formic ester with alcoholic ammonia to 100°; (3) by boiling formic acid with ammonium thiocyanate (B. **16,** 2291). It consists of a thick liquid, miscible with water, alcohol, and ether. Heated rapidly it breaks down into CO and NH_3; P_2O_5 liberates hydrocyanic acid from it. It combines with chloral (p. 201) to form *Chloral Formamide,* $CCl_3.CH(OH)NHCHO$, m.p. 115°, which is employed as a narcotic.

Mercuric oxide dissolves in it with the formation of *mercury formamide,* $(CHO.NH)_2Hg$. It is a feebly alkaline liquid, sometimes applied as a subcutaneous injection. For *sodium formamide,* see C. 1898, I. 927.

Ethyl Formamide, $CHO.NH.C_2H_5$, b.p. 199°, is obtained from ethyl formic ester; also by distilling a mixture of ethylamine with chloral:

$$CCl_3.CHO+NH_2.C_2H_5=CHO.NH.C_2H_5+HCCl_3.$$

Allyl Formamide, b.p.$_{15}$ 109° (B. **28,** 1666).

Formyl Hydrazine, $HCO.NHNH_2$, m.p. 54°, is obtained from formic ester and hydrazine. It yields triazole (B. **27,** R. 801) when heated with formamide.

Diformyl Hydrazine, HCONH.NHCOH, m.p. 106°, is obtained from an excess of formic ester and hydrazine, when heated to 130° (B. **28,** R. 242). Its lead salt with ethyl iodide yields *Diformyl Diethylhydrazine* (B. **27,** 2278).

Hydrocyanic Acid, *Prussic Acid, Formonitrile,* HNC, the *nitrile of formic acid* (see acid nitriles), solidifies −15°, b.p. 26·5°, $D_{18}=0{\cdot}697$, is a powerful poison. It occurs free accumulated in all parts of the Javanese tree, *Pangium edule, Reinw.* (B. **23,** 3548). It is obtained (1) from *amygdalin* (*q.v.*), a glucoside contained in bitter almonds, which, under favourable conditions, takes up water and breaks down into *hydrocyanic acid, lævulose,* and *bitter almond oil* or *benzaldehyde* (*Liebig* and *Wöhler,* A. **22,** 1). An aqueous solution, thus obtained, containing very little hydrocyanic acid, constitutes the officinal *aqua amygdalarum amararum;* its active ingredient is hydrocyanic acid. (2) By the action of phosphorus pentoxide on formamide; (3) synthetically, by subjecting a mixture of acetylene and nitrogen to the influence of the electric spark (*Berthelot*), or by passing it through an electric furnace (C. 1902, I. 525); (4) from cyanogen and hydrogen under the influence of the silent electric discharge; (5) when chloroform is heated, under pressure, with ammonia; (6) upon boiling formoxime (p. 213) with water:

$$\begin{array}{ll}
1. & \underset{\text{Amygdalin.}}{C_{20}H_{27}NO_{11}}+2H_2O=HNC+\underset{\text{Benzaldehyde.}}{C_6H_5CHO}+\underset{\text{Lævulose.}}{2C_6H_{12}O_6} \\
2. & HCONH_2 \xrightarrow{P_2O_5} HNC+H_2O \\
3. & CH\equiv CH \quad + \quad N_2=2HNC \\
4. & CN.CN \quad + \quad H_2=2HNC \\
5. & HCCl_3 \quad +5NH_3=NH_4NC+3NH_4Cl \\
6. & H_2C=N.OH \quad =HNC \quad +H_2O.
\end{array}$$

Hydrocyanic acid is prepared from metallic cyanides, particularly yellow prussiate of potash or potassium ferrocyanide, by the action of dilute sulphuric acid:

$$2K_4Fe(CN)_6+3H_2SO_4=K_2Fe_2(CN)_6+3K_2SO_4+6HNC.$$

The aqueous acid thus obtained may be dehydrated by distillation over calcium chloride or phosphorus pentoxide.

Historical.—Scheele discovered hydrocyanic acid in 1782. *Gay-Lussac,* in 1811, obtained it anhydrous, in the course of his memorable investigations upon the radical cyanogen. In hydrogen cyanide he recognized the hydrogen derivative of a radical, consisting of carbon and nitrogen, for which he suggested the name *cyanogène* (*κύανος, blue, γεννάω, to produce*).

Properties.—Anhydrous hydrocyanic acid is a mobile liquid, possessing a peculiar odour resembling that of oil of bitter almonds, and is extremely poisonous.

It is a feeble acid, imparting a faint red colour to blue litmus. Carbon dioxide decomposes its alkali salts. Like the halogen acids, it reacts with metallic oxides, producing cyanides. From solutions of silver nitrate it precipitates silver cyanide, a white, curdy precipitate (see Inorg. Ch.).

Reactions.—(1) The aqueous acid decomposes readily on standing, yielding ammonium formate and brown substances. The presence of a very slight quantity of stronger acid renders it more stable. When warmed with mineral acids it breaks up into formic acid and ammonia:

$$HNC+2H_2O=HCOOH+NH_3.$$

(2) Dry hydrocyanic acid combines directly with the gaseous halogen acids to form crystalline compounds (p. 244). With hydrochloric acid it probably yields *Formimide Chloride* $(H.CCl{=}NH)_2HCl$ (B. **16,** 352). The acid also unites with some metallic chlorides, *e.g.* Fe_2Cl_6, $SbCl_5$.

(3) Nascent hydrogen (zinc and hydrochloric acid) reduces it to methylamine (p. 158).

(4) When hydrocyanic acid unites with *aldehydes* and *ketones,* the double union between carbon and oxygen in the latter compounds is severed, and cyanhydrins, the *nitriles* of *a-hydroxy-acids,* are produced. These, by this means, are obtained by a nucleus synthesis. This rather important synthesis has become especially interesting for the building up of the aldoses, to which class of derivatives lævulose belongs.

(5) Hydrocyanic acid, or potassium cyanide, unites with many $\alpha\beta$-unsaturated carboxylic acids and $\alpha\beta$-olefine ketones, producing thereby saturated nitrilo-carboxylic acids and nitrilo-ketones, (A. **293,** 338; B. **37,** 4065; C. 1905, I. 171).

For the application of hydrocyanic acid to the synthesis of aromatic aldehydes, see these.

For further addition reactions of hydrocyanic acid, compare formimido ether (p. 243) and isouretine (p. 244).

Constitution.—The production of hydrocyanic acid from formamide on the one side, and its reconversion into ammonium formate, are proofs positive of its being the nitrile of formic acid (see Acid Nitriles). Its formation from chloroform and from acetylene argue also for the formula $H.C{\equiv}N$. The replacement of hydrogen, combined with carbon, by metals is shown also by *acetylene* (p. 288) and other carbon compounds containing negative groups, *e.g.* the *nitroethanes* (p. 151). However, on replacing the metal atoms in the salts by alkyls, two classes of derivatives are obtained. The one series has the alkyls united to carbon, as required by the formula $H.C{\equiv}N$: *nitriles* of monocarboxylic acids, *e.g.* $CH_3.CN$. In the other class the alkyls are joined to nitrogen: *isonitriles* or *carbylamines, e.g.* $CH_3N=C$. The latter are nitrogen-containing derivatives of *carbon monoxide*, and will be discussed after this body. In many respects the behaviour of hydrocyanic acid recalls that of the isonitriles, hence in recent years the formula $HN=C$ has also been assigned to it, and many of the reactions of potassium cyanide conform better with the isonitrile formula, $K.N=C$, than with $K.C\equiv N$, the formula usually given to this salt (A. **287**, 265). Potassium cyanide and iodoalkyls or alkali alkyl sulphuric acids, when heated together yield, in the main, the nitriles; at a lower temperature the isonitriles are formed, which change over into the nitriles at a higher temperature (C. 1900, II. 366). The formation of acetonitrile from hydrocyanic acid and diazomethane is evidence in favour of the nitrile formula of hydrocyanic acid (B. **28**, 857).

Detection.—To detect small quantities of free hydrocyanic acid or its soluble salts, the solution under examination is saturated with potassium hydroxide, a solution of a ferrous salt, containing some ferric salt is added, and the mixture is boiled for a short time. Hydrochloric acid is added to dissolve the precipitated iron oxides; if any insoluble Prussian blue should remain, it would indicate the presence of hydrocyanic acid. The following reaction is more sensitive. A few drops of yellow ammonium sulphide are added to the hydrocyanic acid solution, and this then evaporated to dryness. Ammonium thiocyanate will remain, and if added to a ferric salt, will colour it a deep red.

Polymerization of Hydrocyanic Acid.—When the aqueous acid stands for some time in contact with alkali hydroxides, or with alkali carbonates, or if the anhydrous acid be mixed with a small piece of potassium cyanide, not only brown substances separate, but also white crystals, soluble in ether, and having the same percentage composition as hydrocyanic acid. Inasmuch as they break down, on boiling, into *glycocoll*, $NH_2.CH_2CO_2H$, carbon dioxide and ammonia, they are assumed to be the *nitrile of amidomalonic acid*, $(CN)_2CHNH_2$ (B. **7**, 767). They decompose at 180°, with explosion and partial reformation of hydrocyanic acid.

Salts of Hydrocyanic Acid.—*Cyanides and Double Cyanides.*—The importance of the cyanides and double cyanides in analytical chemistry explains the reason for the discussion of hydrocyanic acid and its salts in inorganic text-books. In organic chemistry the metallic cyanides serve for the introduction of the *cyanogen group* into carbon compounds (comp. *acid nitriles*, *α-ketone acids*, etc.).

The alkali cyanides may be formed by the direct action of these metals on *cyanogen gas;* thus, potassium burns with a red flame in *cyanogen*, at the same time yielding potassium cyanide, $C_2N_2+K_2=2KNC$. They are also produced when nitrogenous organic substances are heated together with alkali metals. The strongly basic metals dissolve in hydrocyanic acid, forming cyanides. A more common procedure is to act with the acid on metallic oxides and hydroxides:

$$HNC+KOH=KNC+H_2O;\quad 2HNC+HgO=Hg(CN)_2+H_2O.$$

The insoluble cyanides of the heavy metals are obtained by the double decomposition of the metallic salts with potassium cyanide.

The cyanides of the light metals, especially the alkali and alkali earths, are easily soluble in water, react alkaline, and are decomposed by acids, even carbon dioxide, with elimination of hydrogen cyanide; yet they are very stable, even at a red heat, and undergo no change. The cyanides of the heavy metals, however, are mostly insoluble, and are only decomposed by strong acids. When ignited, the cyanides of the noble metals undergo decomposition, breaking up into cyanogen gas and metals.

The following simple cyanides are especially important in organic chemistry:

Potassium Cyanide, KNC (Consult v. Richter's "Inorganic Chemistry" for method of preparation, properties, and technical applications of this salt), is as poisonous as hydrocyanic acid itself. The formation of potassium cyanide from the alkali metals and nitrogenous carbon compounds depends on the primary formation of potassium carbide, which then takes up nitrogen.

Its aqueous or alcoholic solution becomes brown on exposure to the air, and decomposes, more rapidly on boiling, into potassium formate and ammonia. When fused in the air, as well as with easily reducible metallic oxides, the salt takes up oxygen and is converted into *potassium isocyanate* (*q.v.*). On being melted with sulphur, it forms potassium thiocyanate (*q.v.*). When the alkyl halides or salts of alkyl sulphuric acid are heated with potassium cyanide, acid nitriles with varying amounts of isomeric carbylamines or isonitriles are produced. Many organic halogen substitution products are converted into nitriles through the agency of potassium cyanide. Ethyl hypochlorite and potassium cyanide yield chlorimidocarbonic ester, a reaction which argues for the isonitrile formula of potassium cyanide (A. **287,** 274).

Ammonium Cyanide, NH_4NC, is formed by the direct union of HNC with ammonia, by heating carbon in ammonia gas; by the action of ammonia on chloroform (p. 239); by the action of the silent electric discharge on *methane* and nitrogen; and by conducting carbon monoxide and ammonia through red-hot tubes. It is best prepared by subliming a mixture of potassium cyanide or dry ferrocyanide with ammonium chloride. It consists of colourless cubes, easily soluble in alcohol, and subliming at 40°, with partial decomposition into NH_3 and HNC. When preserved it becomes dark in colour and decomposes. It unites with aldehydes and ketones with the elimination of water to form α-amidonitriles, *e.g.* with formaldehyde it forms *methylene amidoacetonitrile* (comp. Glycocoll).

Mercuric Cyanide, $Hg(CN)_2$, is obtained by dissolving mercuric oxide in hydrocyanic acid, or by boiling Prussian blue (8 parts) and mercuric oxide (1 part) with water until the blue coloration disappears. It dissolves readily in hot water (in 8 parts cold water), and crystallizes in bright, shining, quadratic prisms. When heated it yields cyanogen and mercury. It forms acetyl cyanide with acetyl chloride (see Pyroracemic Acid).

Silver Cyanide, AgNC, combines with alkyl iodides to yield addition products, which pass into isonitriles when they are heated (p. 247; C. 1903, II. 827).

The chief use of potassium cyanide is in the preparation of acid nitriles of various kinds. This is done by bringing it into double decomposition with alkylogens, alkyl sulphates, and halogen substitution products of the fatty acids. In many instances *mercury cyanide* or *silver cyanide* is preferable, *e.g.* in the formation of *a-ketonic nitriles* from acid chlorides or bromides. It is interesting to note that by the interaction of alkyl iodides and silver cyanide *isonitriles* or *carbylamines* are formed; in them the alcohol radical is joined to nitrogen. (See p. 247 for the explanation.)

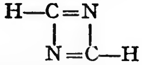
Compound Metallic Cyanides.—The cyanides of the heavy metals, insoluble in water, dissolve in aqueous potassium cyanide, forming crystallizable double cyanides, which are soluble in water. Most of these compounds behave like double salts. Acids decompose them in the cold, with disengagement of hydrocyanic acid and the precipitation of the insoluble cyanides:

$$AgCN.KCN + HNO_3 = AgCN + KNO_3 + HNC.$$

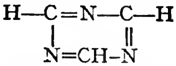
In others, however, the metal is in more intimate union with the cyanogen group, and the metals in these cannot be detected by the usual reagents. Iron, cobalt, platinum, also chromium and manganese in their most highly oxidized state, form cyanogen derivatives of this class. The stronger acids do not eliminate hydrocyanic acid from them, even in the cold, but the corresponding acids are set free, and these are capable of producing salts:

$$K_4Fe(CN)_6+4HCl=H_4Fe(CN)_6+4KCl.$$

Many chemists refer these complex metallic acids to hypothetical, polymeric hydrocyanic acids:



Di-hydrocyanic Acid.



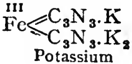
Tri-hydrocyanic Acid.

$Pt{<}{}^{C_2N_2K}_{C_2N_2K}$

Potassium Platinocyanide.

$\overset{II}{Fe}{<}{}^{C_3N_3.K_2}_{C_3N_3.K_2}$

Potassium Ferrocyanide.



$\overset{III}{Fe}{\lessgtr}{}^{C_3N_3.K}_{C_3N_3.K_2}$

Potassium Ferricyanide.

The most important compound metallic cyanides, particularly *potassium ferrocyanide* or *yellow prussiate of potash*, the parent substance for the preparation of cyanogen derivatives, have already been described in the inorganic section of this text-book.

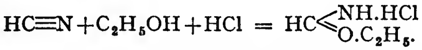
Hydroferrocyanic Acid, $H_4Fe(CN)_6$, is precipitated by ether, from its solution in alcohol, as a pure white compound with ether (C. 1900, II. 1151). This is decomposed at 90° in vacuo. It is assumed that the union occurs at the oxygen atom, which behaves as a tetravalent substance (comp. pp. 127, 128; B. **34,** 3612; **35,** 93).

Sodium Nitroprusside, $Fe(CN)_5(NO)Na_2+2H_2O$.—Hydronitroprussic acid, of which the constitution has not yet been determined (B. **29,** R. 409), is formed when nitric acid acts on potassium ferrocyanide (C. 1897, I. 909). The filtrate from the potassium nitrate is neutralized with sodium carbonate, and yields the salt in beautiful red rhombic prisms, easily soluble in water.

It serves as a very delicate reagent for alkali sulphides and hydrogen sulphide, with which it gives an intense violet coloration.

Formimido-ether, formhydroxamic acid, formyl chloridoxime, methyl nitrolic acid, formamidine, thioformethylimide, and *formamidoxime* are intimately related to hydrocyanic acid and formamide. They are representatives of groups of bodies which will be discussed in connection with acetic acid and its homologues.

The *formimido-ethers*, such as $HC{\lessgtr}{}^{OC_2H_5}_{NH}$, are only known in the form of hydrochlorides. They are obtained from hydrocyanic acid alcohol and HCl (B. **16,** 354, 1644):



$$HC{\equiv}N+C_2H_5OH+HCl = HC{\lessgtr}{}^{NH.HCl}_{O.C_2H_5}.$$

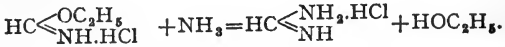
If a mixture of mercuric cyanide and chloride be treated with HCl gas in alcohol-ether solution, a double salt results, $[HC(OC_2H_5):NH]HCl.HgCl_2$ (C. 1904, I. 1064).

Upon standing in contact with alcohols they pass into esters of orthoformic acid (*q.v.*). They yield amidines with ammonia and amines (primary and secondary).

Thioformethylimide, $HC{\lessgtr}{}^{SH}_{NC_2H_5}$, b.p.$_{14}$ 125°, is produced by the union of ethyl isocyanide, in alcoholic solution, with hydrogen sulphide. It is a yellow oil, with an odour like that of sulphur (A. **280,** 297).

Thioformic Acid, HCO.SH, is obtained as its sodium salt when formic phenyl ester (Vol. II.) is hydrolyzed with alcoholic NaSH. The free acid is a very unstable liquid, which quickly polymerizes (C. 1905, I. 20).

Formamidine, *Methenyl Amidine,* $HC\left\langle\begin{matrix}NH_2\\NH\end{matrix}\right.$, is only known in the form of salts. Its hydrochloride is obtained (1) by the action of ammonia on *formimido-ethyl ether hydrochloride* (B. **16,** 375, 1647); (2) from formimide chloride, the addition product of hydrochloric acid and hydrocyanic acid, when it is digested with alcohol:

1. 

$$HC\left\langle\begin{matrix}OC_2H_5\\NH.HCl\end{matrix}\right. + NH_3 = HC\left\langle\begin{matrix}NH_2.HCl\\NH\end{matrix}\right. + HOC_2H_5.$$

2. 

$$2HC\left\langle\begin{matrix}Cl\\NH\end{matrix}\right. + 2C_2H_5OH = HC\left\langle\begin{matrix}NH_2.HCl\\NH\end{matrix}\right. + C_2H_5Cl + HCO_2C_2H_5.$$

Formhydroxamic Acid, $HC\left\langle\begin{matrix}NOH\\OH\end{matrix}\right.$, m.p. 80°, is produced when equimolecular quantities of formic ester and hydroxylamine are allowed to stand in a solution of absolute alcohol; also, by the oxidation of methylamine with persulphuric acid (comp. p. 163) (B. **35,** 4299). It forms brilliant leaflets, which dissolve readily in water and in alcohol, but sparingly in ether. At temperatures above its melting-point violent decomposition takes place, a change which occurs slowly and completely at ordinary temperatures. The acid yields an intense red coloration with ferric chloride. It reduces Fehling's solution, and its mercury salt in dry condition explodes when it is rubbed; *copper salt,* $HCNO_2Cu$ (comp. B. **33,** 1975).

Formyl Chloridoxime, $HC\left\langle\begin{matrix}NOH\\Cl\end{matrix}\right.$, is a beautifully crystallized, very easily decomposed compound, with a sharp, penetrating odour. It is produced when fulminates (p. 249) are treated, in the cold, with concentrated hydrochloric acid. It dissolves in ether. When its solution is warmed with concentrated hydrochloric acid, it rapidly decomposes into formic acid and hydroxylamine hydrochloride:

$$HC\left\langle\begin{matrix}NOH\\Cl\end{matrix}\right. + 2H_2O = H.C\left\langle\begin{matrix}O\\OH\end{matrix}\right. + NH_2OH.HCl.$$

In aqueous solution the body readily reverts to fulminates. Silver nitrate changes it to silver fulminate and silver chloride. Aniline converts it into phenyl isouretine (Vol. II.), and with ammonia it yields cyanisonitrosoacet-hydroxamic acid, a derivative of mesoxalic acid (A. **280,** 303).

Acetyl Formyl Chloride Oxime is obtained from the product of reaction between acetic anhydride, formhydroxamic acid and PCl_5. Silver nitrate converts it into *silver fulminate,* silver chloride, and acetic acid (A. **310,** 19; B. **38,** 3858).

Formonitroxime, *Methyl Nitrolic Acid,* $HC\left\langle\begin{matrix}NO_2\\NOH\end{matrix}\right.$, is prepared from: (1) nitromethane (p. 151) and nitrous acid, and (2) isonitrosoacetic acid (p. 250) and N_2O_4. It is decomposed by boiling with water or dilute acids into N_2O and formic acid, and into HNO_2 and fulminic acid (p. 250) (B. **40,** 418).

Formamidoxime, *Methenyl Amidoxime, Isouretine,* $HC\left\langle\begin{matrix}NH_2\\N(OH)\end{matrix}\right.$, m.p. 114°, is isomeric with *urea,* $CO(NH_2)_2$. It results from the evaporation of an alcoholic solution of hydroxylamine and hydrogen cyanide (*Lossen* and *Schifferdecker,* A. **166,** 295).

Methyl Isouretin, $NH_2CH{:}NOCH_3$, m.p. 40°, is prepared from isouretin, alkali hydroxide, and iodomethane (A. **310,** 2).

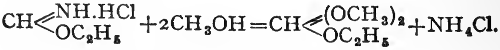
Formazyl Hydride, $HC\left\langle\begin{matrix}N{=}N.C_6H_5\\N{-}NH.C_6H_5\end{matrix}\right.$, m.p. 119–120°, is obtained from formazyl carboxylic acid (see Oxalic Acid derivatives).

Derivatives of Orthoformic Acid (p. 236).

Orthoformic Esters are formed (1) when *chloroform* is heated with sodium alcoholates in alcoholic solution (*Williamson* and *Kay,* A. **92,** 346):

$$CHCl_3 + 3CH_3.ONa = CH(OCH_3)_3 + 3NaCl;$$

(2) when formimido-ethers (p. 243) react with alcohols, mixed esters being also produced (*Pinner,* B. **16,** 1645):



$$CH\left\langle\begin{matrix}NH.HCl\\OC_2H_5\end{matrix}\right. + 2CH_3OH = CH\left\langle\begin{matrix}(OCH_3)_2\\OC_2H_5\end{matrix}\right. + NH_4Cl.$$

They are converted by alcoholic alkali hydroxides into alkali formates, and by glacial acetic acid into acetic esters and ordinary formic esters. Orthoformic ester is changed by ketones and aldehydes into ortho-ethers, *e.g.* $(CH_3)_2C(OC_2H_5)_2$ (p. 235), and acetal, $CH_3.CH(OC_2H_5)_2$ (p. 205). At the same time, it passes also into ordinary formic ether (B. **29**, 1007). Orthoformic ester, in the presence of acetic anhydride and aided by heat, combines with acetyl acetone, acetoacetic ester and malonic ester to yield ethoxymethenyl derivatives (B. **26**, 2729).

Orthoformic Methyl Ester, $CH(OCH_3)_3$, b.p. 102°. *Orthoformic Ethyl Ester*, $CH(OC_2H_5)_3$, b.p. 146°. *Orthoformic Allyl Ester*, $CH(OC_3H_5)_3$, b.p. 196–205° (B. **12**, 115).

Orthothioformic Ester, $CH(SC_2H_5)_3$, b.p.$_{10}$ 116°, is prepared from formic acid ester, or amide, by the action of ethyl mercaptan and hydrochloric acid; also from chloroform and sodium mercaptide. It is a colourless oil of unpleasant odour. It is very stable towards alkalis, but is hydrolized by acids. Permanganate decomposes it into ethane sulphonic acid and methylene diethyl sulphone (B. **40**, 740).

Chloroform, *Trichloromethane*, $CHCl_3$, m.p. —62° (B. **26**, 1053), b.p. 61·5°, $D_{15} = 1·5008$, is obtained: (1) by the chlorination of CH_4 or CH_3Cl; (2) by the action of bleaching powder on different carbon compounds—*e.g.* ethyl alcohol, acetone, etc.; (3) by heating *chloral* (p. 202) and other aliphatic bodies having a terminal CCl_3-group—*e.g.* *trichloracetic acid* and *trichlorophenomalic acid* (*q.v.*)—with aqueous potassium or sodium hydroxide:

$$\underset{\text{Chloral.}}{CCl_3.CHO} + KOH = CHCl_3 + \underset{\text{Potassium Formate.}}{HCO_2K}.$$

Chloroform is prepared technically by treating alcohol and acetone with bleaching powder which acts both as an oxidizing and chlorinating substance. The resulting $CCl_3.CHO$ or $CH_3.CO.CCl_3$ is decomposed by slaked lime (Mechanism of the Reaction: *Zincke*, B. **26**, 501, note). Pure chloroform can be obtained by decomposing pure chloral with potassium hydroxide; or by freezing out crystals of chloroform and then placing this impure substance in a centrifugal machine (*R. Pictet*). Perfectly pure chloroform results in the decomposition of *salicylide-chloroform* (*Anschütz*, A. **273**, 73).

*Historical.**—Chloroform was discovered in 1831 by *Liebig* and *Soubeiran*. It was not until 1835 that *Dumas* proved conclusively that it contained hydrogen. In 1847 *Simpson*, of Edinburgh, introduced chloroform into surgery.

Chloroform is a colourless liquid of an agreeable ethereal odour and sweetish taste. It is an excellent solvent for iodine and many organic substances, some of which crystallize out with "*chloroform of crystallization*," *e.g.* salicylide-chloroform (see above). Chloroform seems to enter into a loose combination with ether, which is evidenced by a rise of temperature when the two liquids are mixed. Inhalation of its vapours produces anæsthesia. It is uninflammable. It forms C_6Cl_6 when it is conducted through tubes heated to redness.

Reactions.—(1) Chloroform is oxidized by the prolonged action of sunlight in presence of the oxygen of the air to phosgene (C. 1905, II. 1623), to prevent which about one per cent. of alcohol is added. Chromic acid also converts chloroform into this body.

(2) Chlorine converts chloroform into CCl_4.

(3) When heated with aqueous or alcoholic potassium hydroxide it forms potassium formate (p. 236) and carbon monoxide. The latter is probably a

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* Der Schutz des Chloroforms vor Zersetzung am Licht und sein erstes Vierteljahrhundert: E. Biltz, 1892. Der Aether gegen den Schmerz, C. Binz, 1896, S. 54.

product of reaction with the $=OCl_2$ group, which is formed by the expulsion of HCl from the chloroform by the action of the alkali. It then unites with the alkali, whereby the more formic acid is produced the higher the temperature of reaction (A. **302**, 274):

$$CHCl_3+4KOH=HCOOK+3KCl+2H_2O.$$

(4) Orthoformic acid ester, $CH(O.C_2H_5)_3$, is produced when chloroform is treated with sodium alcoholate.

(5) When heated to 180° with alcoholic ammonia, it forms ammonium cyanide and chloride. When potassium hydroxide is present, an energetic reaction takes place at ordinary temperatures. The equation is:

$$CHCl_3+NH_3+4KOH=KNC+3KCl+4H_2O.$$

(6) *Isonitriles* (p. 247), having extremely disgusting odours, are formed when chloroform is heated with primary bases and potassium hydroxide. This reaction serves both for the detection of chloroform and also of the primary amines.

(7) Chloroform yields an additive product with acetone—*e.g.* *a*-hydroxy-isobutyric acid.

(8) It is converted by sodium acetoacetic ester into m-hydroxyuvitic acid (Vol. II.).

(9) Aromatic hydroxyaldehydes (Vol. II.) are produced when chloroform is digested with phenols and sodium hydroxide.

Bromoform, $CHBr_3$, m.p. 7·8°, b.p. 151°, $D_{15}=2·9$, is produced by the action of bromine and KOH or lime (*Löwig*, 1832) on alcohol or acetone; by electrolysis of a solution of acetone and potassium bromide (C. 1902, I. 455; 1904, II. 301); from chloroform and aluminium bromide (C. 1900, I. 1201; 1901, I. 666); and also from tribromopyroracemic acid (*q.v.*).

Iodoform, CHI_3, m.p. 120°, is formed when iodine and potassium hydroxide act on ethyl alcohol, acetone, aldehyde and other substances containing the methyl group. Pure methyl alcohol, however does not yield iodoform (B. **13**, 1002).

The formation of *tri-iodoaldehyde* and *tri-iodoacetone* precedes the production of the iodoform. These substances are very unstable in the presence of alkalis. When tri-iodoacetic acid is warmed with acetic acid, or when it is treated with alkali carbonates, it breaks down into iodoform and carbon dioxide. Iodoform can be obtained by electrolysis of an aqueous solution of KI, Na_2CO_3 and alcohol, or KI and acetone (C. 1897, II. 695; 1898, I. 31; 1900, II. 19; 1904, I. 995). Acetylene-mercury chloride, $C_2H_2.HgCl_2$, also yields iodoform when acted on by iodine and alkali (C. 1902, II. 1499).

Iodoform crystallizes in brilliant, yellow leaflets, or hexagonal plates (C. 1899, I. 189; 1901, II. 23), soluble in alcohol and ether, but insoluble in water. Its odour is saffron-like. It evaporates at medium temperatures and distils in aqueous vapour. Digested with alcoholic KOH, HI, or potassium arsenite, it passes into *methylene iodide* (p. 206). Light and air decompose iodoform into CO_2, CO, I, and water (C. 1905, II. 1718).

Historical.—Iodoform was discovered in 1832 by *Serullas*. *Dumas*, in 1834, proved that it contained hydrogen, and in 1880 it was applied by *Mosetig-Moorhof* in Vienna in the treatment of wounds.

Fluoroform, CHF_3, is obtained from silver fluoride and chloroform, or better, iodoform mixed with sand. It is a gas (B. **23**, R. 377, 680; C. 1900, I. 886).

Fluorochloroform $CHCl_2F$., b.p. 14·5°; *Fluorochlorobromoform*, $CHClFBr$, b.p. 38° (B. **26**, R. 781).

Nitroform, *Trinitromethane*, $CH(NO_2)_3$, has been described already, in connection with the nitroparaffins (p. 155).

Formyl Trisulphonic Acid, *Methine Trisulphonic Acid*, $CH(SO_3H)_3$, is produced by the action of sodium sulphite on *chloropicrin*, $CCl_3(NO_2)$ (*q.v.*), and when fuming sulphuric acid acts on *calcium methyl sulphonate* (p. 210). The acid is very stable, even in the presence of boiling alkalis (C. 1899, I. 182).

In this connection may be mentioned also *dibromonitromethane* (p. 151), *nitromethane disulphonic acid* (A. **161**, 161), and *hydroxymethane disulphonic acid*, $CH(OH)(SO_3H)_2$ (B. **6**, 1032); *dichloromethane monosulphonic acid, dichloromethyl alcohol*, are only known as acetic esters.

Carbon Monoxide, Isonitriles or Carbylamines, and Fulminic Acid.

Carbon Monoxide, CO, m.p.$_{100}$ $-207°$, b.p.$_{760}$ $-190°$, critical temperature $-141°$, critical pressure 35 atmospheres, a colourless, combustible gas, the product of the incomplete combustion of carbon, has already been discussed in the inorganic section of this book. The methods for its production and its reactions, which are of importance in organic chemistry, will again be briefly reviewed. Carbon monoxide is obtained (1) from formic acid, oxalic acid, α-ketonic acids such as pyroracemic acid and benzoyl formic acids (Vol. II.); (2) from α-hydroxy-acids such as glycolic acid, lactic acid, malic acid, citric acid, and mandelic acid (Vol. II.); (3) from tertiary carboxylic acids of the formula R_3COOH, such as trimethyl acetic acid (p. 258), triphenylacetic acid (Vol. II.), camphoric acid, cineolic acid (Vol. II.), from all these by the action of concentrated or fuming sulphuric acid (comp. B. **39**, 51). It is also made from hydrocyanic acid if, in preparing the latter from potassium ferrocyanide, $K_4Fe(CN)_6.3H_2O$, concentrated sulphuric acid be substituted for the more dilute acid; in this manner the hydrocyanic acid is changed to formamide, and the latter immediately breaks down into ammonia and carbon monoxide. Formamide yields carbon monoxide on the application of heat.

Reactions.—(1) Carbon monoxide and hydrogen exposed to the influence of electric discharges yield *methane* (p. 71). Being an unsaturated compound, carbon monoxide unites (2) with oxygen, giving a feebly luminous but beautifully blue flame, forming *carbon dioxide*; (3) with sulphur yielding *carbon oxysulphide*; and (4) with chlorine, to form *carbon oxychloride* or phosgene. It is rather remarkable that it also combines directly with certain metals. (5) With potassium it forms *potassium carbon monoxide* or *potassium hexoxybenzene* (*q.v.*), $C_6O_6K_6$; (6) with nickel it yields *nickel carbonyl*, $Ni(CO)_4$, b.p. 43° (*Mond*, *Quincke*, and *Langer*, B. **23**, R. 628; C. 1093, I. 1250; 1904, II. 1111); (7) with iron it yields iron carbonyl $Fe(CO)_5$, b.p. 102° (C. 1906, I. 333; 1907, I. 1179). It forms (8) alkali formates with the alkali hydroxides (p. 236), and with (9) sodium methoxide and sodium ethoxide it yields sodium acetate and propionate.

Carbon Monosulphide, CS, is not yet known (B. **28**, R. 388).

Isonitriles, Isocyanides, or **Carbylamines** are isomeric with the *alkyl cyanides* or the *acid nitriles*, but are distinguished from these in that they have their alkyl group joined to nitrogen. The isonitriles were first prepared in 1866 by *Gautier* (A. **151**, 239) by two methods. The first consisted in allowing alkyl iodides (1 mol.) to act on silver cyanide (p. 242) (2 mols.), whilst in the second method the addition products of silver cyanide and the alkyl isonitriles were decomposed by distillation with potassium cyanide:

$$1a. \quad C_2H_5I+2AgCN=C_2H_5NC.AgCN+AgI$$
$$1b. \quad C_2H_5NC.AgCN+KCN=C_2H_5NC+AgCN.KCN.$$

Shortly afterwards, *A. W. Hofmann* (A. **146**, 107) found that isonitriles were produced by digesting chloroform and primary amines with alcoholic potassium hydroxide:

$$2. \quad C_2H_5NH_2+CHCl_3+3KOH=C_2H_5NC+3KCl+3H_2O.$$

3. The isonitriles are produced as by-products in the preparation of the nitriles from alkyl iodides or sulphates and potassium cyanide.

Properties.—The carbylamines are colourless liquids which can be distilled, and possess an exceedingly disgusting odour. They are sparingly soluble in water, but readily soluble in alcohol and ether.

Reactions.—(1) The isonitriles are characterized by their decomposition by dilute acids into *formic acid* and primary amines. This reaction proceeds readily by the action of dilute acids (HCl), or by heating with water to 180°:

$$C_2H_5.NC+2H_2O=C_2H_5NH_2+HCO_2H.$$

Nitriles, on the other hand, by the absorption of water, pass into the ammonium salts of carboxylic acids:

$$C_2H_5CN+2H_2O=C_2H_5COONH_4.$$

It is, therefore, concluded that in the nitriles the alkyl group is in union with carbon, whilst in the isonitriles it is linked to nitrogen. Three formulæ have been suggested for the isonitriles:

$$\text{I. } C_2H_5\overset{III}{N}=\overset{II}{C} \qquad \text{II. } C_2H_5\overset{III}{N}=\overset{IV}{C}= \qquad \text{III. } C_2H_5\overset{V}{N}\equiv\overset{IV}{C}.$$

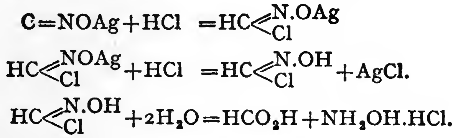
Nef, who has studied several aromatic isonitriles exhaustively, gives formula I, the preference (A. **270**, 267). (2) The fatty acids convert isonitriles into alkylized fatty acid amides. (3) The isonitriles, like hydrocyanic acid (p. 240), form crystalline derivatives with HCl; these are probably the hydrochlorides of alkyl formimide chlorides, $2CH_3NC.3HCl = [CH_3N=CHCl]_2HCl$, which water decomposes into formic acid and amino- bases. (4) Mercuric oxide changes the isonitriles into isocyanic ethers, $C_2H_5N=CO$, with the separation of mercury, just as CO, by absorption of oxygen, becomes CO_2.

(5) Heat converts the isonitriles into the normal nitriles, $RC \vdots N$, with intermediate polymerization products (C. 1907, I. 948).

(6) Iodo-alkyls and metallic cyanides unite with the isonitriles to form *double compounds* (see above); RNC.CNAg can be looked on as being an ester of a hydrosilvercyanic acid, $HAg(CN)_2$ (C. 1903, II. 827; 1907, I. 948).

Methyl Isocyanide, *Methyl Carbylamine*, *Isoacetonitrile*, CH_3NC, b.p. 59°. **Ethyl Isocyanide**, *Ethyl Carbylamine*, C_2H_5NC, b.p. 79°, when heated at from 230° to 250°, undergoes atomic rearrangement into propionitrile. It combines with chlorine to yield ethyl isocyanogen chloride or ethylimidocarbonyl chloride, a derivative of carbonic acid; similarly, with bromine to form ethyl carbylamine bromide (C. 1904, II. 29). With H_2S it forms thioformethylimide (p. 243), and with acetyl chloride it produces ethylimidopyruvyl chloride, a derivative of pyroracemic acid (A. **280**, 291). n-*Propyl Isocyanide*, b.p. 98°. n-*Butyl Isocyanide*, b.p. 119° (C. 1900, II. 366).

Fulminic Acid, *Carbyloxime*, C=N.OH, is the oxime corresponding with carbon monoxide, and possesses the properties and characteristics of a strong acid (*R. Scholl*, B. **23,** 3506; *Nef*, A. **280,** 303; comp. also, B. **27,** 2817). The fulminates have the same percentage composition as the salts of cyanic acid, and constitute one of the first examples of isomeric compounds (*Liebig*, 1823). Little is known about the free acid. Its odour is very similar to that of hydrocyanic acid, and is as poisonous. The acid is formed when the fulminates are decomposed by strong acids. It combines quite readily with the latter,—*e.g.* it yields formyl chloridoxime with hydrochloric acid (p. 244), which breaks down very easily with the formation of fulminic acid. The reaction of the fulminates with hydrochloric acid affords some insight into the consitution of fulminic acid itself. First, hydrochloric acid unites directly and salts of formyl chloridoxime arise, from which, by the absorption of water, formic acid and hydroxylamine are formed:



$$\mathrm{C{=}NOAg+HCl} = \mathrm{HC}{<}\begin{smallmatrix}\mathrm{N.OAg}\\ \mathrm{Cl}\end{smallmatrix}$$

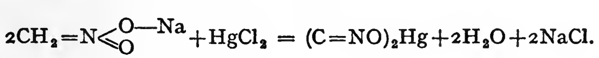
$$\mathrm{HC}{<}\begin{smallmatrix}\mathrm{NOAg}\\ \mathrm{Cl}\end{smallmatrix}+\mathrm{HCl} = \mathrm{HC}{<}\begin{smallmatrix}\mathrm{N.OH}\\ \mathrm{Cl}\end{smallmatrix}+\mathrm{AgCl}.$$

$$\mathrm{HC}{<}\begin{smallmatrix}\mathrm{N.OH}\\ \mathrm{Cl}\end{smallmatrix}+2\mathrm{H_2O} = \mathrm{HCO_2H+NH_2OH.HCl}.$$

The most important of the salts is mercury fulminate, which is employed, technically, as a detonating agent.

Historical.—Mercury fulminate was first obtained by *Howard*, in 1800, by the interaction of a solution of mercuric nitrate and alcohol. In 1824, *Liebig* and *Guy Lussac* showed that silver fulminate possesses the same percentage composition as silver cyanate, discovered by *Wohler* in 1822—an observation which paved the way for the recognition of the phenomenon of isomerism (p. 25). *Kekulé* (1856) considered fulminic acid to be nitro-acetonitrile, NO_2CH_2CN, an assumption which could not be sustained, since in 1883 *Ehrenberg* and *Carstanjer*, and also *Steiner*, found that all the nitrogen in fulminic acid appears as hydroxylamine when the acid is treated with hydrochloric acid. *Steiner* ascribed to fulminic acid the formula C(NOH) : C(NOH). In 1890, however, *R. Scholl* put forward the formula C=NOH, indicating that fulminic acid is the oxime of carbon monoxide; this *Nef* completely substantiated in 1894 by thorough experimental investigation (B. **33,** 51).

Mercury Fulminate, $(\mathrm{C{=}N.O})_2\mathrm{Hg}+\frac{1}{2}\mathrm{H_2O}$ (B. **18,** R. 148), is formed (1) by the action of *alcohol* (B. **9,** 787; **19,** 993, 1370), acetaldehyde, dimethyl acetal or malonic acid (C. 1901, II. 404) on a solution of mercury in excess of nitric acid which contains oxides of nitrogen (B. **38,** 1345); (2) by the addition of a solution of sodium nitromethane to a mercuric chloride solution:

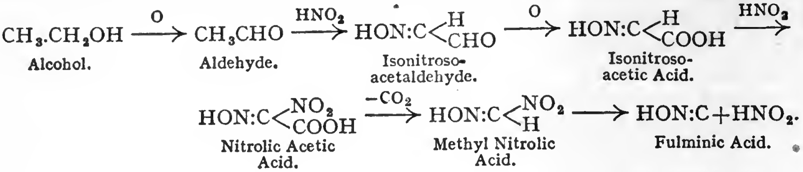


$$2\mathrm{CH_2{=}N}{<}\begin{smallmatrix}\mathrm{O{-}Na}\\ \mathrm{O}\end{smallmatrix}+\mathrm{HgCl_2} = (\mathrm{C{=}NO})_2\mathrm{Hg}+2\mathrm{H_2O}+2\mathrm{NaCl}.$$

There is always produced at the same time a *yellow* basic salt, $(\mathrm{Hg}{<}\begin{smallmatrix}\mathrm{O}\\ \mathrm{O}\end{smallmatrix}{>}\mathrm{C{=}NO})_2\mathrm{Hg}$, which is the sole product obtained on pouring a solution of mercuric chloride into a solution of sodium nitromethane. This yellow salt is also very explosive.

(3) By boiling methyl nitrolic acid (p. 154) with dilute nitric acid

in presence of mercury salts. This reaction indicates the course of the formation of fulminic acid from alcohol (B. **40,** 421):



$$CH_3.CH_2OH \xrightarrow{O} CH_3CHO \xrightarrow{HNO_2} HON{:}C{<}^{H}_{CHO} \xrightarrow{O} HON{:}C{<}^{H}_{COOH} \xrightarrow{HNO_2}$$

Alcohol. Aldehyde. Isonitroso-acetaldehyde. Isonitroso-acetic Acid.

$$HON{:}C{<}^{NO_2}_{COOH} \xrightarrow{-CO_2} HON{:}C{<}^{NO_2}_{H} \longrightarrow HON{:}C+HNO_2.$$

Nitrolic Acetic Acid. Methyl Nitrolic Acid. Fulminic Acid.

The formation of fulminic acid from malonic acid (p. 249) proceeds similarly to the above.

Fulminating mercury crystallizes in shining, white needles, which are fairly soluble in hot water. It explodes violently on percussion, and also when acted on by concentrated sulphuric acid. Concentrated hydrochloric acid evolves CO_2, and yields hydroxylamine hydrochloride and formic acid, a reaction well adapted for the preparation of hydroxylamine (B. **19,** 993).

Chlorine gas decomposes mercury fulminate into mercuric chloride, cyanogen chloride and CCl_3NO_2. Aqueous ammonia converts it into urea and guanidine (see acetyl isocyanate). Silver fulminate in benzene solution is converted by aluminium chloride into β-benzaldoxime (B. **32,** 3492).

Silver Fulminate, $C{=}NOAg$, white needles, is prepared after the manner of the mercury salt, and is even more explosive than the latter. It is also prepared from acetoformyl chloridoxime (p. 244) and $AgNO_3$: $\begin{matrix}H\\Cl\end{matrix}{>}C{=}NOCOCH_3 \xrightarrow{2AgNO_3}$ $AgCl+CNOAg+HOCOCH_3$. Potassium chloride precipitates from hot solutions of silver fulminate one atom of silver as chloride, and the *double salt*, $C_2N_2O_2AgK$, crystallizes from the solution. Nitric acid precipitates from this salt *acid silver fulminate*, $C_2N_2O_2AgH$, a white, insoluble precipitate. On boiling mercury fulminate with water and copper or zinc, metallic mercury is precipitated and *copper* and *zinc fulminates* ($C_2N_2O_2Cu$ and $C_2N_2O_2Zn$) are produced.

Sodium fulminate, $C{=}NONa$, is obtained when mercury fulminate is digested with sodium amalgam in alcohol. It crystallizes in fine needles, is explosive and poisonous. Examined by the freezing-point method, its molecule is found to be a simple one (B. **38,** 1355; A. **298,** 345). A solution acidified with sulphuric acid yields to ether a crystalline explosive *acid* $(CNOH)_3$. Sodium fulminate is converted to an *ester* $(CNOCH_3)_3$, m.p. 149°, by means of dimethyl sulphate (C. 1907, I. 27).

In the formation of salts and double salts fulminic acid behaves much like hydrocyanic acid. This is readily understood if hydrocyanic acid be regarded as hydrogen isocyanide, $C{=}NH$. Sodium ferrocyanide corresponds with *sodium ferrofulminate,* $(C{=}NO)_6FeNa_4+18H_2O$, which is produced by bringing together a solution of sodium fulminate and ferrous sulphate (A. **280,** 335). It consists of yellow needles.

Dibromonitro-acetonitrile, *Dibromoglyoxime Peroxide,* $CN.CBr_2NO_2$, or $\begin{array}{l}BrC{=}N{-}O\\ Br\dot{C}{=}N{-}\dot{O}\end{array}$ m.p. 50°, is produced when bromine acts on mercury fulminate. This body, when heated with hydrochloric acid, passes into HBr, NH_3, NH_2OH and *oxalic acid.* Aniline probably converts the dibromide into the dioxime of the oxanilide $(C_6H_5NHC{=}NOH)_2$.

Fulminuric Acid, *Nitrocyanacetamide,* $C_3N_3O_3H_3{=}CN.CH(NO_2)CONH_2$, is a derivative of tartronic acid. Its alkali salts are obtained by boiling mercuric fulminate with potassium chloride or ammonium chloride and water. The sodium salt is converted, by a mixture of sulphuric and nitric acids, into trinitroacetonitrile. The free acid is obtained by decomposing the lead salt with hydrogen sulphide. It deflagrates at 145°. Especially characteristic is the *Cuprammonium salt,*

$C_3N_3O_3H_3(CuNH_3)$, which consists of glistening purple-coloured prisms. (Comp. Cyanuric Acid.)

Ethyl iodide converts the silver salt at 80–90° into the *Ethyl Ester*, $C_3H_2N_3O_2(OC_2H_5)$, m.p. 133°, which is changed into **Desoxyfulminuric Acid**, *Cyanisonitroso-acetamide*, $C_3N_3H_3O_2 = CN.C(:NOH)CONH_2$, m.p. 184° (A. **280**, 331), a mesoxalic acid derivative, when boiled with water and alcohol.

ACETIC ACID AND ITS HOMOLOGUES, THE FATTY ACIDS, $C_nH_{2n+1}.CO_2H$

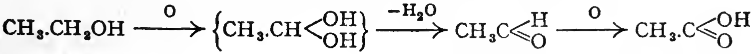
We can regard and also designate all the homologues of acetic acid as mono-, di-, and tri-alkylized acetic acids. Names are then obtained which as clearly express the constitution of the acids as the *carbinol* names show the constitution of the alcohols (p. 101).

The acids of this series are known as *fatty acids*, because their higher members occur in the natural fats. The latter are esters of the fatty acids, with glycerol, a trihydric alcohol. On boiling them with potassium or sodium hydroxide, alkali salts (soaps) of the fatty acids are formed, and from these the mineral acids liberate the fatty acids. Hence, the process of converting a compound ester into an acid and an alcohol has been termed *saponification*, and this term has been applied to the conversion of other derivatives of the acids into the acids themselves—*e.g.* the conversion of nitriles into the corresponding acids.*

The lower acids (with exception of the first members) are oils; the higher, commencing with *capric acid*, are solids at ordinary temperatures. The first can be distilled without decomposition; the latter are partially decomposed, and can only be distilled without alteration under reduced pressure. Only the first members are volatile in steam. Acids of similar structure show an increase in their boiling points of about 19° for each increase in CH_2. It may be remarked that the melting points are higher in acids of normal structure, containing an even number of carbon atoms, than in the case of those having an odd number of carbon atoms. The dibasic acids exhibit the same characteristic. As the oxygen content diminishes, the specific gravities of the acids grow successively less, and the acids themselves at the same time approach the hydrocarbons in character. The lower members are readily soluble in water, but the solubility regularly diminishes with increasing molecular weight. All dissolve readily in alcohol, and very easily in ether. Their solutions redden blue litmus. The acidity diminishes with increasing molecular weight; this is very clearly evidenced by the diminution of the heat of neutralization and the initial velocity in the etherification of the acids.

The most important general methods of preparation of the monobasic acids are:

(1) Oxidation of the primary alcohols and aldehydes:



$$CH_3.CH_2OH \xrightarrow{O} \left\{CH_3.CH<^{OH}_{OH}\right\} \xrightarrow{-H_2O} CH_3C\lessgtr^{H}_{O} \xrightarrow{O} CH_3.C\lessgtr^{OH}_{O}$$

Ethyl Alcohol. **Aldehyde.** **Acetic Acid.**

The oxidizing agents most usually employed are chromic acid and permanganate (C. 1907, I. 1179).

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* The term *hydrolysis* is more strictly accurate.—Tr.

In the case of normal primary alcohols with high molecular weight the conversion into the corresponding acids is effected by heating with soda-lime:

$$\underset{\text{Cetyl Alcohol.}}{C_{15}H_{31}CH_2OH}+NaOH=\underset{\text{Sodium Palmitate.}}{C_{15}H_{31}.CO_2Na}+2H_2.$$

(2) By the addition of hydrogen to the unsaturated monocarboxylic acids:

$$\underset{\text{Acrylic Acid.}}{CH_2=CH.CO_2H}+2H=\underset{\text{Propionic Acid.}}{CH_3.CH_2.CO_2H}.$$

(3) By the reduction of hydroxy-acids at raised temperatures by means of hydriodic acid:

$$CH_3.CH(OH)CO_2H+2HI=CH_3.CH_2.CO_2H+H_2O+I_2.$$

Or, halogen substituted acids may be reduced by means of sodium amalgam.

Many nucleus-synthetic methods are known for the formation of derivatives of the acids, which can easily be changed to the latter. These methods are important in the building-up of the acids.

(4) *Synthesis of the Acid Nitriles.*—The alkyl cyanides, called also the *fatty acid nitriles*, are produced by the interaction of potassium cyanide and alkylogens or the alkali salts of the alkyl sulphuric acids. When the alkyl cyanides or fatty acid nitriles are heated with alkalis or dilute mineral acids the cyanogen group is transformed into the carboxyl group, whilst the nitrogen is changed to ammonia. In this manner formic acid is produced from hydrocyanic acid (p. 236):

$$CH_3.CN+2H_2O+HCl=CH_3.CO_2H+NH_4Cl$$
$$CH_3.CN+H_2O+KOH=CH_3.CO_2K+NH_3.$$

This method makes the synthesis of acids from alcohols possible.

The change of the nitriles to acids is, in many instances, best carried out by digesting the former with sulphuric acid (diluted with an equal volume of water); the fatty acid will then appear as an oil upon the surface of the solution (B. **10**, 262).

The conversion of the nitriles directly into esters of the acids may be effected by dissolving them in alcohol and passing hydrochloric acid gas into the solution, or by warming it with sulphuric acid (B. **9**, 1590).

(5) The action of carbon monoxide on the sodium alcoholates heated to 160–200° only proceeds smoothly and easily in the case of sodium methoxide and ethoxide (A. **202**, 294; C. 1903, II. 933):

$$\underset{\text{Sodium Ethoxide.}}{C_2H_5.ONa+CO}=\underset{\text{Sodium Propionate.}}{C_2H_5.CO_2.Na}.$$

Similarly, carbon monoxide and sodium hydroxide yield formic acid (p. 236).

(6*a*) The action of carbon dioxide on sodium alkyls (A. **111**, 234) is only applicable with sodium methyl and sodium ethyl (p. 184). It may be compared with that in which formic acid is produced by the action of moist carbon dioxide on potassium (potassium hydride):

$$C_2H_5.Na+CO_2=C_2H_5.CO_2Na.$$

(6*b*) By the action of carbon dioxide on an ethereal solution of an alkyl magnesium halide, and the decomposition of the resulting magnesium compound by ice and sulphuric acid (C. 1901, II. 622; B. **35**, 2519):

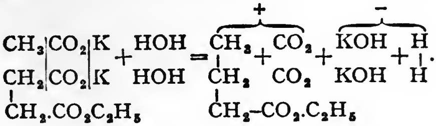
$$CH_3MgBr\xrightarrow{CO_2}CH_3CO_2MgBr\xrightarrow{H_2O}CH_3COOH.$$

(7) By the action of phosgene gas, $COCl_2$, on the zinc alkyls. Acid chlorides are first formed, and subsequently yield acids when treated with water:

$$Zn(CH_3)_2+2COCl_2=\underset{\text{Acetyl Chloride.}}{2CH_3.COCl}+ZnCl_2,\ \text{and}$$

$$CH_3.COCl+H_2O=\underset{\text{Acetic Acid.}}{CH_3.CO.OH}+HCl.$$

(8) Electro-syntheses of the esters of monocarboxylic acids occur upon electrolyzing mixtures of the salts of fatty acids and the mono-esters of dicarboxylic acids. Butyric ester, for example, is obtained from potassium acetate and potassium ethyl succinate (B. **28**, 2427):



$$\begin{array}{l}\mathrm{CH_3|CO_2|K}\\ \mathrm{CH_2|CO_2|K}\\ \quad|\\ \mathrm{CH_2.CO_2C_2H_5}\end{array}+\begin{array}{c}\mathrm{HOH}\\ \mathrm{HOH}\end{array}=\overbrace{\begin{array}{l}\mathrm{CH_3}\\ \quad|\\ \mathrm{CH_2}\\ \quad|\\ \mathrm{CH_2{-}CO_2.C_2H_5}\end{array}+\begin{array}{c}\mathrm{CO_2}\\ \\ \mathrm{CO_2}\end{array}}^{+}+\overbrace{\begin{array}{c}\mathrm{KOH}\\ \mathrm{KOH}\end{array}+\begin{array}{c}\mathrm{H}\\ |\\ \mathrm{H}\end{array}}^{-}.$$

The following *methods of formation* are based upon the *breaking-down of long carbon chains:*

(9) The decomposition of ketones by oxidation with potassium dichromate and sulphuric acid (p. 219):

$$\underset{\text{Pentadecyl Methyl Ketone from Palmitic Acid.}}{\mathrm{CH_3[CH_2]_{14}.CO.CH_3}} \xrightarrow{\mathrm{O}} \underset{\text{Pentadecyclic Acid.}}{\mathrm{CH_3[CH_2]_{13}CO_2H}} + \underset{\text{Acetic Acid.}}{\mathrm{CH_3.CO_2H}}$$

By the action, also, of chlorine and alkali, the alkyl methyl ketones can be made to yield chiefly carboxylic acids, the change being due to the separation of the CH_3 group in the form of chloroform and the replacement of it by the hydroxyl group.

(10) Decomposition of unsaturated acids by fusion with potassium hydroxide:

$$\underset{\text{Potassium Angelicate.}}{\mathrm{CH_3CH:C(CH_3)CO_2K}} \xrightarrow{\mathrm{KOH}} \underset{\text{Potassium Acetate.}}{\mathrm{CH_3CO_2K}} \text{ and } \underset{\text{Potassium Propionate.}}{\mathrm{CH_3CH_2.CO_2K}}.$$

(11) Decomposition of acetoacetic ester, as well as mono- and dialkyl acetoacetic esters, by concentrated alcoholic potassium hydroxide:

$$\underset{\text{Acetoacetic Ester.}}{\mathrm{CH_3CO.CH_2CO_2C_2H_5}} + \mathrm{2KOH = CH_3CO_2K + CH_3CO_2K + C_2H_5OH}$$

$$\mathrm{CH_3CO.CH(R)CO_2C_2H_5 + 2KOH = CH_3CO_2K + CH_2(R)CO_2K + C_2H_5.OH}$$

$$\mathrm{CH_3CO.C(R)_2CO_2C_2H_5 + 2KOH = CH_3CO_2K + CH(R)_2CO_2K + C_2H_5.OH.}$$

The mono- and di-alkyl acetoacetic esters are decomposed, by boiling sodium alcoholate solution, into mono- and di-alkyl acetic ester.

(12) Decomposition of ketoxime carboxylic acids, after internal rearrangement into acid amides. This reaction is valuable in determining the constitution of the olefine carboxylic acids, from which the ketoxime carboxylic acids can be prepared. (Comp. oleic acid, p. 300.)

(13) Decomposition of dicarboxylic acids, in which the two carboxyl groups are in union with the same carbon atom. On the application of heat, these lose carbon dioxide:

$$\underset{\text{Malonic Acid.}}{\mathrm{CH_2}{<}\begin{matrix}\mathrm{CO_2H}\\ \mathrm{CO_2H}\end{matrix}} \longrightarrow \mathrm{CH_3.CO_2H + CO_2}$$

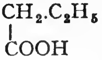
$$\mathrm{CH(R)}{<}\begin{matrix}\mathrm{CO_2H}\\ \mathrm{CO_2H}\end{matrix} \longrightarrow \mathrm{CH_2(R)CO_2H + CO_2}$$

$$\mathrm{C(R)_2}{<}\begin{matrix}\mathrm{CO_2H}\\ \mathrm{CO_2H}\end{matrix} \longrightarrow \mathrm{CH(R)_2CO_2H + CO_2.}$$

The acids produced by the methods 11 and 13 can be regarded as directly derived from acetic acid, $CH_3.COOH$, in which 1 or 2H atoms of the CH_3-group are replaced by alkyls; hence the designations *methyl-* and *dimethyl-acetic acid*, etc.:

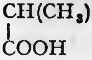
$$\begin{array}{l} CH_2.CH_3 \\ | \\ COOH \end{array}$$

Methyl Acetic Acid or Propionic Acid.



$$\begin{array}{l} CH_2.C_2H_5 \\ | \\ COOH \end{array}$$

Ethyl Acetic Acid or Butyric Acid.



$$\begin{array}{l} CH(CH_3)_2 \\ | \\ COOH \end{array}$$

Dimethyl Acetic Acid or Isobutyric Acid.

To comprehend fully the importance of these two methods of formation the following facts may be stated here, though they are out of their pre-arranged sequence.

Acetic ester is the parent substance for the production of acetoacetic ester, and chloracetic ester for that of malonic ester. *Acetoacetic ester*, $CH_3CO.CH_2CO.OC_2H_5$, and *malonic ester*, $CH_2(COOC_2H_5)_2$, contain a CH_2-group, in combination with two CO-groups. One hydrogen atom in a CH_2-group thus situated may be replaced by sodium, and the latter, through the agency of an alkyl iodide, by an alkyl group. In this manner *monoalkyl acetoacetic esters*, $CH_3CH.CHRCO.OC_2H_5$, and *monoalkyl malonic esters*, $CHR(COOC_2H_5)_2$, are obtained. Further, in these monoalkylic derivatives the second hydrogen atom of the CH_2-group may be substituted by sodium, and this, in turn, may be replaced by a similar or a different alcohol radical, through the action of an alkylogen: the products are then *dialkyl acetoacetic esters*, CH_3-$CO.C(R)_2COOC_2H_5$, and *dialkyl malonic esters*, $C(R)_2(COOC_2H_5)_2$. The ease with which all of the reactions involved in the formation of the alkyl malonic and acetoacetic esters are carried out render these bodies very convenient material for the production of a nucleus synthesis of mono- and dialkyl acetic acids. The breaking-down of malonic acid and the alkyl malonic acids possesses this advantage, that it proceeds in one direction only, whereas the alkyl acetoacetic esters undergo a *ketone decomposition* simultaneously with the *acid decomposition*, with the separation of the carboxyl group (p. 218).

Isomerism.—Every monocarboxylic acid corresponds with a primary alcohol. Hence the number of isomeric monocarboxylic acids of definite carbon content is, as in the instance of the aldehydes, equal to that of the possible primary alcohols (p. 103), possessing a like quantity of carbon. The isomerism is dependent upon the isomerisms of the hydrocarbon radicals in union with the carboxyl group.

There are no possible isomers of the first three members of the series $C_nH_{2n}O_2$:

$H.CO_2H$	$CH_3.CO_2H$	$C_2H_5.CO_2H$
Formic Acid.	Acetic Acid.	Propionic Acid.

Two structural isomers are possible for the fourth member, $C_4H_8O_2$:

$CH_3.CH_2.CH_2.CO_2H$ and	$(CH_3)_2.CH.CO_2H$.
Propyl Carboxylic Acid Butyric Acid.	Isopropyl Carboxylic Acid. Isobutyric Acid.

Four isomers are possible with the fifth member, $C_5H_{10}O_2 = C_4H_9.CO_2H$, inasmuch as there are four butyl, C_4H_9, groups, etc.

Reactions.—A concise review of their many derivatives was given in the introduction to the monocarboxylic acids, which were obtainable in part from the acids, or directly from their salts. Their most important reactions follow:

(1) Acids and alcohols yield *esters* in the presence of hydrochloric or sulphuric acid (p. 263).

(2) Salts and alkylogens, or alkyl sulphates, yield *esters*.

(3) Acids or salts, when acted on by the chlorides of phosphorus, yield *acid chlorides* (p. 269) and *acid anhydrides* (p. 271).

(4) The ammonium salts of the acids lose water and become *acid amides* (p. 274) and *acid nitriles* (p. 278).

(5) The halogens produce substitution products.

(6) The fatty acids are very stable in the presence of oxidizing agents, and are only attacked very slowly. Those acids, containing a tertiary group, yield nitro-derivatives (B. **15**, 2318; **32**, 3661) when acted on by nitric acid.

In discussing the *paraffins*, their *alcohols*, *aldehydes* and *ketones*, methods of producing these bodies were described, which were based upon reactions of the fatty acids, their salts or their immediate derivatives. These may be summarized here:

(1) *Paraffins* (p. 74) result from the reduction of higher fatty acids by hydriodic acid.

(2) *Paraffins* (p. 74) are produced when the calcium salts of the fatty acids are distilled with soda-lime.

(3) *Paraffins*, together with CO_2, alcohols, and other products (p. 73), result from the electrolysis of concentrated solutions of the potassium salts of the fatty acids.

(4) Acid chlorides and anhydrides, when reduced, yield *aldehydes* (p. 191) and *primary alcohols* (p. 103).

(5) Acid chlorides, esters, amides, and nitriles reacting with zinc alkyls or magnesium alkyl halides yield *ketones* (p. 217) and *tertiary alcohols* (p. 105).

(6) By the interaction of iodine and the silver salts of fatty acids, esters of the next lower alcohol are formed (comp. p. 263).

(7) When the calcium salts are distilled with calcium formate, *aldehydes* are produced (p. 190).

(8) *Simple* and *mixed ketones* (p. 190) are formed when a single calcium salt or an equimolecular mixture of two different calcium salts are distilled respectively.

(9) The reduction of acid nitriles yields *primary amines*; these, are converted into the corresponding alcohols by nitrous acid.

(10) Acid amides, when acted on by bromine and sodium hydroxide, lose CO as carbon dioxide and pass into the next lower series of *primary amines*. This reaction can therefore be employed for proceeding step by step down the series of fatty acids (p. 263). The azides of the acids behave similarly when acted on by water or alcohol.

The constitution of the fatty acids follows from their production from bodies of known constitution and their conversion into the same.

Acetic Acid [Ethane Acid], $CH_3.COOH$ (*Acidum aceticum*), m.p. 16·7°, b.p. 118° $D_{20}=1·0497$, formed by the spontaneous souring of alcoholic liquids, is the acid which has been longest known. Vinegar and the term "acid" were designated, for example, by the Romans by closely related words. Wood vinegar first became known in the middle ages.

Acetic acid is found in the vegetable kingdom both free and in the form of salts and esters. Thus, it was mentioned under n-hexyl and n-octyl alcohols that they occurred in the form of their *acetic esters* in the ethereal oil of the seed of *Heracleum giganteum* and in the fruit of *Heracleum sphondylium*. The officinal, concentrated acid, as well as the thirty per cent. aqueous solution of the acid, are applied medicinally.

Acetic acid is produced in the decay of many organic substances and in the dry distillation of wood, sugar, tartaric acid, and other compounds; also in the oxidation of numerous carbon derivatives, as it is very stable towards oxidants.

The methods of forming acetic acid, which have any particular theoretical value, have already been discussed under the general methods for the production of fatty acids (p. 251); therefore they will be but briefly noticed here:

(1) The oxidation of ethyl alcohol and acetaldehyde.

(2) The reduction of hydroxyacetic acid or glycollic acid, $CH_2(OH).CO_2H$, and the reduction of chlorinated acetic acids—*e.g.* trichloracetic acid, $CCl_3.CO_2H$.

Synthetically: (3) From methyl cyanide or acetonitrile.

(4) From sodium methoxide and carbon monoxide.

(5) From sodium methyl or magnesium methyl iodide and carbon dioxide.

(6) From phosgene and zinc methyl.

By decomposition: (7) By the oxidation of acetone and many mixed methyl ketones.

(8) By the decomposition of many unsaturated acids of the oleic series when fused with potassium hydroxide.

(9) From acetoacetic ester by means of alcoholic potassium hydroxide.

(10) By heating malonic acid.

Finally, a rather remarkable synthesis consists in allowing air and potassium hydroxide to act on acetylene in diffused daylight (*Berthelot*, 1870):

$$CH{\equiv}CH+H_2O+O=CH_3.COOH.$$

Historical.—At the close of the eighteenth century *Lavoisier* recognized the fact that air was necessary for the conversion of alcohol into acetic acid, and that its volume was correspondingly diminished during the process. In 1830 *Dumas* converted the acid, by means of chlorine, into trichloracetic acid; whilst the reconversion of the latter into the parent acid, by potassium amalgam and water, was demonstrated by *Melsens* in 1842. But when, in 1843, *Kolbe* succeeded in producing *trichloracetic acid* (p. 287) from its elements, the first synthesis of acetic acid was accomplished.

Acetic acid is produced (1) by the oxidation of ethyl alcohol and liquids containing this alcohol. It is customary, depending upon their origin, to distinguish *wine vinegar*, *fruit vinegar*, and *malt vinegar*.

(1) **The Quick-vinegar Process** (*Schützenbach*, 1823).—The acetic fermentation of alcoholic liquids consists in the transference of the oxygen of the air to the alcohol (*Pasteur*). This is effected by the acetic ferment, the "mother of vinegar,"—*Mycoderma aceti*, *Micrococcus aceti*, or *Bacterium aceti*,*—the germs of which are always present in the air. In this process, by an enlargement of the contact surface of the alcoholic liquid with the air, there ensues an accelerated oxidation. Large wooden tubs are filled with shavings previously moistened with vinegar, upon which diluted (ten per cent.) alcoholic solutions are poured. The lower part of the tub, exposed in a warm room (25–30°), is provided with a sieve-like bottom, and all about it are holes permitting the entrance of air to the interior. The liquid collecting on the bottom is run through the same process two or three times, to ensure the conversion of all the alcohol into acetic acid.

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* Vorlesungen über Bacterien von A. de Bary, 1887. Die Gährungschemie von Adolf Mayer, 1895.

(2) *Wood Vinegar Process.*—Considerable quantities of acetic acid are also obtained by the dry distillation of wood in cast-iron retorts, a process already referred to when discussing methyl alcohol (p. 109). The aqueous distillate, consisting of acetic acid, wood spirit, acetone, and empyreumatic oils, is neutralized with soda, evaporated to dryness, and the residual sodium salt heated to 230–250°. In this manner, the greater portion of the various organic admixture is destroyed, sodium acetate remaining unaltered. The salt purified in this way is distilled with sulphuric acid, when acetic acid is set free and purified by further distillation over potassium chromate.

Properties.—Anhydrous acetic acid at low temperatures consists of a leafy, crystalline mass—*glacial acetic acid*—which, on melting, forms a liquid of sharp and penetrating odour. It mixes with water in all proportions; at first a contraction ensues, consequently the specific gravity increases until the composition of the solution corresponds with the *hydrate*, $C_2H_4O_2+H_2O$ ($=CH_3.C(OH)_3$), $D_{15}=1{\cdot}0754$ (77–80 per cent.). On further dilution, the specific gravity becomes less, until a 43 per cent. solution possesses about the same specific gravity as anhydrous acetic acid. Ordinary vinegar contains about 5 per cent. of acetic acid. Acetic acid is an excellent solvent for many carbon compounds. Even the halogen acids dissolve readily in glacial acetic acid (B. **11**, 1221). Pure acetic acid should not decolorize a drop of potassium permanganate solution. It may be detected by conversion into volatile acetic ether when heated with alcohol and sulphuric acid (p. 267), or by the formation of cacodyl oxide (p. 176).

Acetates.—The acid combines with one equivalent of the bases, forming readily soluble, crystalline salts. It also forms basic salts with iron, aluminium, lead and copper; these are sparingly soluble in water. The alkali salts have the additional property of combining with a molecule of acetic acid, yielding *acid* salts, such as $C_2H_3O_2K+C_2H_4O_2$, acid potassium acetate.

Potassium Acetate, $C_2H_3O_2K$, deliquesces in the air and dissolves readily in alcohol. The *acid* salt, $C_2H_3KO_2.C_2H_4O_2$, m.p. 148°, crystallizes out in pearly leaflets. The *salt*, $C_2H_3O_2K+2C_2H_4O_2$, m.p. 112°, is decomposed at 170° into acetic acid and the neutral salt.

Sodium Acetate, $C_2H_3O_2Na+3H_2O$, crystallizes in large, rhombic prisms, which effloresce on exposure. When heated, the anhydrous salt remains unchanged at 310°.

Ammonium Acetate, $C_2H_3O_2NH_4$, is a crystalline mass. Heat applied to the dry salt converts it into water and acetamide (C. 1903, I. 386). *Calcium Acetate*, $(C_2H_3O_2)_2Ca+H_2O$, and *Barium Acetate*, $(C_2H_3O_2)_2Ba+H_2O$, dissolve readily in water.

Ferrous Acetate, $(C_2H_3O_2)_2Fe$, readily oxidizes in aqueous solution to insoluble basic ferric acetate. *Ferric Acetate*, $(C_2H_3O_2)_6Fe_2$, is not crystallizable. On boiling, basic ferric acetate is precipitated. *Aluminium Acetate* behaves similarly. Both salts are employed as mordants in dyeing, as they are capable of uniting with the cotton fibre. The basic salts produced on the application of heat are capable of retaining *dyes*.

Normal Lead Acetate, $(C_2H_3O_2)_2Pb+3H_2O$, is obtained by dissolving litharge in acetic acid. The salt forms brilliant four-sided prisms, which effloresce on exposure. It possesses a sweet taste (hence called *sugar of lead*), and is poisonous. If an aqueous solution of lead acetate be boiled with litharge, *basic lead acetates*, of varying lead content, *e.g.* $C_2H_3O_2PbOH$ and $C_2H_3O_2Pb.O.Pb.O.Pb.C_2H_3O_2$, are produced. These solutions react alkaline, and absorb carbon dioxide from the air, depositing *basic carbonates* of lead—*white lead*.

Lead Tetra-acetate, $(C_2H_3O_2)_4Pb$ is obtained when minium is dissolved in hot glacial acetic acid. From the filtrate colourless monoclinic prisms separate; m.p. 175° (B. **29**, R. 342; C. 1903, 1879).

Copper Acetate, $(C_2H_3O_2)_2Cu+H_2O$, is easily soluble in water. *Basic copper* salts occur in commerce under the name of *verdigris*. They are obtained by dissolving copper strips in acetic acid in presence of air. The double salt of acetate and arsenite of copper is the so-called *Schweinfurt Green*.

Silver Acetate, $C_2H_3O_2Ag$, separates in brilliant needles or leaflets. The salt is soluble in 98 parts water at 14° C.

The *decompositions of the acetates* have already been considered; summarized they are:

(1) Potassium acetate, when electrolyzed, yields *ethane* (p. 73).

(2) Sodium acetate, heated with soda-lime, yields *methane* (p. 72).

(3) Potassium acetate and arsenious oxide, on the application of heat, yield *cacodylic oxide* (p. 177).

(4) Ammonium acetate loses water when heated, with the formation of *acetamide* (p. 277).

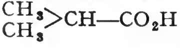
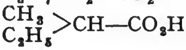
(5) Calcium acetate is decomposed by heat into *acetone* (p. 190, 222).

(6) Calcium acetate and calcium formate, heated together, yield *aldehyde* (p. 190).

(7) Calcium acetate and the calcium salts of higher fatty acids when heated yield mixed methyl alkyl ketones (p. 190).

PROPIONIC ACID. BUTYRIC ACIDS. VALERIC ACIDS

The following table contains the melting points (B. **29**, R. 344), the boiling points, and the specific gravities of the normal acids and their isomers:—

Name.	Formula.	M. P.	B. P.	Specific Gravity.
Propionic Acid, Methyl Acetic Acid	$CH_3CH_2—CO_2H$	—36·5°	140°	0·9920 (18°)
n-Butyric Acid, Ethyl Acetic Acid	$CH_3(CH_2)_2CO_2H$	—	163°	0·9587 (20°)
Isobutyric Acid, Dimethyl Acetic Acid	 $\begin{matrix}CH_3\\CH_3\end{matrix}>CH—CO_2H$	—79°	155°	0·9490 (20°)
n-Valeric Acid, n-Propyl Acetic Acid	$CH_3(CH_2)_3CO_2H$	—59°	186°	0·9568 (0°)
Isovaleric Acid, Isopropyl Acetic Acid	$C_3H_7CH_2—CO_2H$	—51°	174°	0·9470 (0°)
Methyl Ethyl Acetic Acid	 $\begin{matrix}CH_3\\C_2H_5\end{matrix}>CH—CO_2H$	—	175°	0·9410 (21°)
Trimethyl Acetic Acid, Pivallic Acid	$(CH_3)_3C.CO_2H$	+35°	163°	—

Propionic Acid, *Methyl Acetic Acid* [Propane Acid], $CH_3.CH_2.CO_2H$, may be prepared by the methods in general use in making fatty acids; (1) by the oxidation of n-propyl alcohol and propyl aldehyde with chromic acid; (2) by reduction of *acrylic acid* (p. 294) and *propargylic acid* (p. 303); (3) by reduction of *lactic acid*, $CH_3.CH(OH).CO_2H$, and glyceric acid, $CH_2OH.CHOH.CO_2H$; (4) (*synthetically*) from *ethyl alcohol* by its conversion, through ethyl iodide, into ethyl cyanide or propionitrile; (5) from sodium ethoxide and carbon monoxide; (6) from sodium ethyl or magnesium ethyl bromide and carbon dioxide; (7) (*by decomposition*) in the oxidation of methyl ethyl, methyl propyl and diethyl ketone; (8) by the action of alcoholic potassium hydroxide on methyl acetoacetic ester with the simultaneous production of ethyl methyl ketone; (9) from methyl malonic acid or isosuccinic acid by the application of heat.

Its formation from malate and lactate of calcium by fermentation is worthy of note (B. **12,** 479; **17,** 1190). *Gottlieb* first discovered propionic acid in 1847, when he fused sucrose with potassium hydroxide. *Dumas* gave the acid its name, derived from *πρῶτος, the first, πίων, fat,* because when treated in aqueous solution with calcium chloride it separated as an oil. It is the first acid which in its behaviour approaches the higher fatty acids.

The *barium salt,* $(C_3H_5O_2)_2Ba+H_2O$, crystallizes in rhombic prisms: *silver salt,* $C_3H_5O_2Ag$, dissolves sparingly in water.

Butyric Acids, $C_4H_8O_2$.

Two isomeric acids are possible:

(1) **Normal Butyric Acid,** *Ethyl Acetic Acid* [Butane Acid], *butyric acid of fermentation,* occurs free and also as the glycerol ester in the vegetable and animal kingdoms, especially in the butter of cows (to the amount of about five per cent., together with glycerides of palmitic and oleic acids), in which Chevreul found it, in the course of his classic investigations upon the fats. It exists as hexyl ester in the oil of *Heracleum giganteum,* and as octyl ester in *Pastinaca sativa.* It has been observed free in the perspiration and in the body fluids. It may be obtained by the usual methods employed for the preparation of fatty acids, and is produced in the butyric fermentation of sugar, starch and lactic acid, and in the decay and oxidation of proteins.

Ordinarily the acid is obtained by the fermentation of sugar or starch, induced by the previous addition of decaying substances, *e.g.* cheese, in the presence of calcium or zinc carbonate, which are intended to neutralize the acids as they form. According to *Fitz,* the butyric fermentation of glycerol or starch is most advantageously evoked by the direct addition of schizomycetes, especially *Bacillus subtilis* and *Bacillus boocopricus* (B. **11,** 49, 53; **29,** 2726).

Butyric acid is a thick, rancid-smelling liquid, which solidifies when cooled. It dissolves readily in water and alcohol, and may be thrown out of solution by salts.

The *calcium salt,* $(C_4H_7O_2)_2Ca+H_2O$ (A. **213,** 67), yields brilliant leaflets, and is less soluble in hot than in cold water (in 3·5 parts at 15°); therefore the latter grows turbid on warming (B. **30,** 2956).

(2) **Isobutyric Acid,** *Dimethyl Acetic Acid* [Methylpropane Acid], $(CH_3)_2.CH.CO_2H$, is found free in St. John's Bread, the pod of the carob- or locust-tree, *Ceratonia siliqua,* as octyl ester in the oil of *Pastinaca sativa,* and as ethyl ester in croton oil. It is prepared according to the general methods (p. 251). Concentrated nitric acid converts it into *dinitropropane* (p. 155); and potassium permanganate oxidizes it to α-hydroxyisobutyric acid.

Isobutyric acid bears great similarity to normal butyric acid, but is not miscible with water.

The *calcium salt,* $(C_4H_7O_2)_2Ca+5H_2O$, dissolves more readily in hot than in cold water.

Valeric Acids, $C_5H_{10}O_2$. There are four possible isomers (comp. table, p. 258):

(1) **Normal Valeric Acid,** *n-Propylacetic Acid* [Pentane Acid], $CH_3.(CH_2)_3.CO_2H$, is formed according to the usual methods (p. 251, *et seq.*).

Ordinary valeric acid occurs free, and as esters in the animal and vegetable kingdoms, chiefly in the small valerian root (*Valeriana officinalis*), and in the root of *Angelica Archangelica,* from which it may be isolated by boiling with water or a soda solution. It is a mixture of isovaleric acid with the optically active methyl ethyl acetic acid, and is therefore also active. A similar artificial mixture may be obtained by oxidizing the amyl alcohol of fermentation (p. 120) with chromic acid mixture. Valeric acid combines with water and yields a *hydrate,* $C_5H_{10}O_2+H_2O$, soluble in 26·5 parts of water at 15°.

(2) **Isovaleric Acid,** *Isopropyl Acetic Acid* [3-Methyl-butane Acid], $(CH_3)_2.CH.CH_2.CO_2H$, may be synthetically obtained by some of the methods described on p. 252. It is an oily liquid with an odour resembling that of valerian.

Potassium permanganate oxidizes isovaleric acid to β-hydroxyisovaleric acid, $(CH_3)_2.C(OH).CH_2.CO_2H$. Concentrated nitric acid attacks, in addition, the CH-group, forming *methyl hydroxysuccinic acid, β-nitroisovaleric acid,* $(CH_3)_2.C(NO_2).CH_2.CO_2H$, and *β-dinitropropane,* $(CH_3)_2C(NO_2)_2$ (B. **15,** 2324). (Comp. the behaviour of isobutyric acid.)

The *isovalerates* generally have a greasy feel. When thrown in small pieces upon water they have a rotary motion, dissolving at the same time; *barium salt,* $(C_5H_9O_2)_2Ba$; *calcium salt,* $(C_5H_9O_2)_2Ca+3H_2O$, forms stable, readily soluble needles; *zinc salt,* $(C_5H_9O_2)_2Zn+2H_2O$, crystallizes in large, brilliant leaflets; when the solution is boiled a basic salt separates.

(3) **Methyl Ethyl Acetic Acid,** [2-Methyl-butane Acid], $\begin{smallmatrix}CH_3\\C_2H_5\end{smallmatrix}>\overset{*}{C}H.CO_2H$, contains an asymmetric carbon atom, and, like its corresponding alcohol (p. 120), may exist in two optically active and one optically inactive modification. The optically inactive form has been synthesized, and has also been resolved by means of its brucine salts into its optically active components. The *l*-salt dissolves with difficulty. The specific rotatory power of the optically active methyl ethyl acetic acid is $[\alpha]_D = \pm 17° 85'$ (B. **32,** 1089).

Calcium salt, $(C_5H_9O_2)_2Ca+5H_2O$.

An optically active *methyl ethyl acetic* acid is present in valerian and angelica roots together with isopropyl acetic acid, as already mentioned, and also in the products of oxidation of fermentation amyl alcohol (A. **204,** 159). Pure *d*-methyl ethyl acetic acid is prepared by the oxidation of pure *l*-amyl alcohol (p. 120) (B. **37,** 1045); and has been found in the break-down products of convolvulin (Vol. II.).

(4) **Trimethyl Acetic Acid,** *Pivalic Acid,* [Dimethyl-propane Acid], $(CH_3)_3.C.CO_2H)$, is formed from tertiary butyl iodide, $(CH_3)_3CI$ (p. 134), by means of the cyanide; also by the oxidation of pinacoline (p. 224). The acid is soluble in 40 parts H_2O at 20°, and has an odour resembling that of acetic acid.

Barium salt, $(C_5H_9O_2)_2Ba+5H_2O$; *calcium salt,* $(C_5H_9O_2)_2Ca+5H_2O$ (C. 1898, I. 202).

HIGHER FATTY ACIDS

The subjoined table contains the melting and boiling points of the higher fatty acids, beginning with those containing six carbon atoms. The boiling points enclosed in parentheses were determined under 100 mm. pressure:

Name.	Formula.	M. P.	B. P.
n-Hexoic Acid, n-Caproic Acid	$CH_3.(CH_2)_4CO_2H$	+8°	205°
Isobutyl Acetic Acid (B. 27, R. 191)	$(CH_3)_2CH[CH_2]_2CO_2H$	—	198°
sec.-Butyl Acetic Acid (B. 26, R. 931)	$(C_2H_5)(CH_3)CHCH_2CO_2H$	—	174°
Diethyl Acetic Acid	$\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\!>\!CHCO_2H$	— —	190° 193°
Methyl n-Propyl Acetic Acid Methyl Isopropyl Acetic Acid	$\left.\begin{matrix}CH_3\\C_3H_7\end{matrix}\right\}\!>\!CHCO_2H$	—	191°
Dimethyl Ethyl Acetic Acid	$\begin{matrix}(CH_3)_2\\C_2H_5\end{matrix}\!\geqslant\!CCO_2H$	−14°	187°
n-Heptoic Acid, Œnanthylic Acid	$CH_3(CH_2)_5CO_2H$	−10·5°	223°
Methyl n-Butyl Acetic Acid	$\begin{matrix}CH_3\\C_4H_9\end{matrix}\!>\!CHCO_2H$	—	210°
Ethyl n-Propyl Acetic Acid	$\begin{matrix}C_2H_5\\C_3H\end{matrix}\!>\!CHCO_2H$	—	209°
Methyl Diethyl Acetic Acid	$\begin{matrix}CH_3\\(C_2H_5)_2\end{matrix}\!\geqslant\!CCO_2H$	—	208°
n-Octoic Acid, Caprylic Acid	$CH_3(CH_2)_6CO_2H$	16·5°	237°
n-Nonoic Acid, Pelargonic Acid	$CH_3(CH_2)_7CO_2H$	12·5°	254°
Capric Acid	$CH_3(CH_2)_8CO_2H$	31·4°	270°
n-Undecylic Acid	$CH_3(CH_2)_9CO_2H$	28·5°	(212·5°)
Lauric Acid	$CH_3(CH_2)_{10}CO_2H$	43·5°	(225°)
n-Tridecylic Acid	$CH_3(CH_2)_{11}CO_2H$	40·5°	(236°)
n-Myristic Acid	$CH_3(CH_2)_{12}CO_2H$	53·8°	(220·5°)
n-Pentadecatoic Acid (B. 27, R. 191)	$CH_3(CH_2)_{13}CO_2H$	51°	(260°)
Palmitic Acid	$CH_3(CH_2)_{14}CO_2H$	62°	(278·5°)
Margaric Acid	$CH_3(CH_2)_{15}CO_2H$	59·9°	(280·5°)
Stearic Acid	$CH_3(CH_2)_{16}CO_2H$	69·2°	(291°)
Di-n-octyl Acetic Acid	$[CH_3(CH_2)_7]_2CHCO_2H$	38·5°	—
Arachidic Acid	$C_{20}H_{40}O_2$	75°	—
Behenic Acid	$C_{22}H_{44}O_2$	83°	—
Cerotic Acid	$C_{26}H_{52}O_2$ or $C_{27}H_{54}O_2$	78°	—
Melissic Acid	$C_{30}H_{60}O_2$	90°	—

The normal fatty acids in the preceding list, having an even number of carbon atoms, occur almost exclusively in the natural oils and fats, which are chiefly glycerides of these acids. Palmitic and stearic acids possess great technical importance.

Caproic Acid, n-*Hexoic Acid,* $CH_3(CH_2)_4CO_2H$, occurs in the form of its glycerol ester in cow's butter, goat butter, and in coconut oil. It is produced, together with butyric acid, in the butyric fermentation.

Œnanthylic Acid, n-*Heptoic Acid,* $CH_3(CH_2)_5CO_2H$, can easily be obtained as an oxidation product of *œnanthol* (p. 201).

Caprylic Acid, n-*Octoic Acid,* $CH_3(CH_2)_6CO_2H$, occurs as its glycerol ester in goat butter and in many fats and oils; also in the fusel-oil of wine.

Pelargonic Acid, n-*Nonoic acid,* $CH_3(CH_2)_7CO_2H$, is present in the leaves of *Pelargonium roseum*, and is prepared by the oxidation of oleic acid and oil of rue (methyl n-nonyl ketone, p. 224). It may also be obtained by the fusion of undecylenic acid with potassium hydroxide.

Capric Acid, n-*Decylic Acid,* $CH_3(CH_2)_8CO_2H$, is present in butter, goat butter, in coconut oil and in many fats, and as its amyl ester in fusel oil. It is the first normal acid that is solid at the ordinary temperature.

n-Undecylic Acid, $CH_3(CH_2)_9CO_2H$, is obtained by reduction of undecylenic acid from castor oil.

Lauric Acid, n-*Dodecylic Acid,* $CH_3(CH_2)_{10}CO_2H$, occurs as its glycerol ester in the fruit of laurels, *Laurus nobilis,* in coconut oil (C. 1904, I. 259), and in pichurim beans. It is found as its *cetyl ester* in spermaceti.

Myristic Acid, n-*Tetradecylic Acid,* $CH_3.(CH_2)_{12}CO_2H$, occurs in muscat butter (from *Myristica moschata*), in spermaceti and coconut, in *myristin* (B. **18,** 2011; **19,** 1435), in earth-nuts (B. **22,** 1743), in ox-bile (B. **25,** 1829), and as free acid, as well as its methyl ester, in iris root (B. **26,** 2677).

Palmitic Acid, n-*Hexadecylic Acid,* $CH_3(CH_2)_{14}CO_2H$.—The glycerol ester of this acid and that of stearic acid and oleic acid are the principal constituents of solid animal fats. Palmitic acid occurs in rather large quantities, partly uncombined, in palm oil. Spermaceti is the *cetyl ester* of the acid, whilst the *myricyl ester* is the chief constituent of beeswax. The acid is most advantageously obtained from olive oil, which consists almost exclusively of the glycerides of palmitic and oleic acids; also, from Japan wax, a glyceride of palmitic acid (B. **21,** 2265). The acid is artificially made by heating cetyl alcohol with soda lime to 270°; also by fusing together *oleic acid* and potassium hydroxide.

Margaric Acid, n-*Heptadecylic Acid,* $CH_3(CH_2)_{15}CO_2H$, does not apparently exist naturally in the fats (B. **38,** 1247). It is made in the laboratory by boiling cetyl cyanide with potassium hydroxide.

Stearic Acid, n-*Octodecylic Acid,* $CH_3(CH_2)_{16}CO_2H$, is associated with palmitic and oleic acids as a mixed glyceride in solid animal fats —the tallows. Its name is derived from *στέαρ*=tallow.

Arachidic Acid, $CH_3(CH_2)_{18}CO_2H$, occurs in earth-nut oil (from *Arachis hypogæa*). It has been obtained synthetically from acetoacetic ester and octodecyl iodide (from stearyl aldehyde) (B. **17,** R. 570). For products derived from arachidic acid, see B. **29,** R. 852. *Theobromic Acid,* m.p. 72°, derived from cacao butter, appears to be identical with arachidic acid.

Behenic Acid, $C_{22}H_{44}O_2$, is found in the oil obtained from *Moringa oleïfera,* and has been prepared by the reduction of iodobehenic acid from erucic acid (B. **27,** R. 577; C. 1897, II. 1101).

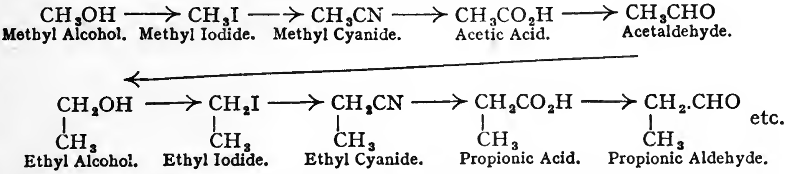
Cerotic Acid, $C_{26}H_{52}O_2$ or $C_{27}H_{54}O_2$ (B. **30,** 1418), occurs together with melissic acid, in a free condition in *beeswax,* and may be extracted from this by means of boiling alcohol. As its ceryl ester, it is the chief constituent of *Chinese wax* (B. **30,** 1415). Its name is derived from *cera*=wax.

Melissic Acid, $C_{30}H_{60}O_2$, m.p. 88°, is formed from myricyl alcohol (p. 121) when the latter is heated with soda-lime. It is a waxy substance, and appears to be a mixture of two acids.

The acids mentioned in the table, but not described here, have been prepared by the usual synthetic methods. Some of them will be encountered later in the form of oxidation or reduction products of complicated, complex aliphatic derivatives.

SYNTHESIS AND DECOMPOSITION OF THE FATTY ACIDS

The synthetic methods for the production of the fatty acids are not all equally well adapted for this purpose. Thus, methods 5, 6, and 7 (p. 252) are restricted to the synthesis of the simplest members of the series. Reactions more satisfactory than these, and especially fitted for the synthesis of the higher mono- and dialkyl acetic acids, are based on the behaviour of acetoacetic ester and malonic ester (methods 11 and 13). However, trialkylacetic acids cannot be synthesized in this way. It is only the fourth method of formation—the synthesis of an acid cyanide from the iodide of an alcohol containing an atom less of carbon than the cyanide and the acid derived from it—that will lead to the synthesis of not only mono- and di-, but also of trialkyl acetic acids. The nitriles of the latter—*e.g.* of *trimethyl acetic acid*, *dimethyl ethyl acetic acid*, and *diethyl methyl acetic acid*—have been obtained from the iodides of the corresponding tertiary alcohols. The nitrile synthesis renders the formation of acids from alcohols possible, and inasmuch as acids can be reduced to aldehydes and alcohols by the fourth transposition method (p. 255), the synthesis of these two classes of bodies is made possible. *Lieben*, *Rossi*, and *Janecek* (A. **187**, 126), beginning with methyl alcohol, systematically prepared the normal acids and corresponding alcohols up to *œnanthic acid*, according to the following scheme:



$$\underset{\text{Methyl Alcohol.}}{CH_3OH} \longrightarrow \underset{\text{Methyl Iodide.}}{CH_3I} \longrightarrow \underset{\text{Methyl Cyanide.}}{CH_3CN} \longrightarrow \underset{\text{Acetic Acid.}}{CH_3CO_2H} \longrightarrow \underset{\text{Acetaldehyde.}}{CH_3CHO}$$

$$\longleftarrow$$

$$\underset{\text{Ethyl Alcohol.}}{\begin{array}{l}CH_2OH\\|\\CH_3\end{array}} \longrightarrow \underset{\text{Ethyl Iodide.}}{\begin{array}{l}CH_2I\\|\\CH_3\end{array}} \longrightarrow \underset{\text{Ethyl Cyanide.}}{\begin{array}{l}CH_2CN\\|\\CH_3\end{array}} \longrightarrow \underset{\text{Propionic Acid.}}{\begin{array}{l}CH_2CO_2H\\|\\CH_3\end{array}} \longrightarrow \underset{\text{Propionic Aldehyde.}}{\begin{array}{l}CH_2.CHO\\|\\CH_3\end{array}} \quad \text{etc.}$$

The following reactions come into consideration in the breaking-down or decomposition of the normal fatty acids:

(1) The method of formation 9 (p. 253) of carboxylic acids: oxidation of mixed methyl n-alkyl ketones, in which the CO-group remains in combination with the methyl group.

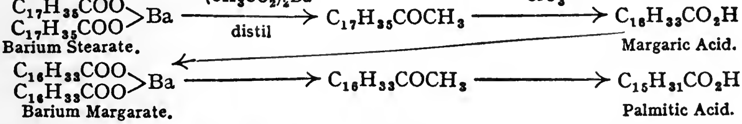
(2) The reaction 10 (p. 255) of acid amides with bromine and potassium hydroxide.

(3) The action of iodine on the silver salts.

(4) The oxidation of the olefine carboxylic acids, produced by bromination and subsequent abstraction of HBr.

(5) The heating of α-hydroxy-fatty acids, obtained from α-bromo- fatty acids, whereby the next lower aldehyde is obtained (comp. pp. 192, 193).

1. The first of these reactions was employed systematically by *F. Krafft* for the breaking-down of stearic acid into normal fatty acids of known constitution, from which it was concluded that stearic acid and the lower homologues derived from it possessed normal constitution. Upon distilling *barium stearate*, $(C_{17}H_{35}CO_2)_2Ba$, and *barium acetate*, $(CH_3CO_2)_2Ba$, *heptadecyl methyl ketone*, $C_{17}H_{35}COCH_3$, results. When this is oxidized it breaks down into *margaric acid*, $C_{16}H_{33}CO_2H$, and acetic acid. *Barium margarate* and barium acetate yield *hexadecyl methyl ketone*, $C_{16}H_{33}.CO.CH_3$, and this, by oxidation, passes into *palmitic acid*, $C_{15}H_{31}CO_2H$, and acetic acid, etc.:



$$\underset{\text{Barium Stearate.}}{\begin{array}{l}C_{17}H_{35}COO\\C_{17}H_{35}COO\end{array}{>}Ba} \xrightarrow[\text{distil}]{(CH_3CO_2)_2Ba} C_{17}H_{35}COCH_3 \xrightarrow{CrO_3} \underset{\text{Margaric Acid.}}{C_{16}H_{33}CO_2H}$$

$$\longleftarrow$$

$$\underset{\text{Barium Margarate.}}{\begin{array}{l}C_{16}H_{33}COO\\C_{16}H_{33}COO\end{array}{>}Ba} \longrightarrow C_{16}H_{33}COCH_3 \longrightarrow \underset{\text{Palmitic Acid.}}{C_{15}H_{31}CO_2H}$$

2. *A. W. Hofmann* (B. **19**, 1433) discovered the second method, which will be treated more fully in connection with the acid amides and nitriles (pp. 158, 274); here only the diagrammatic representation of the course of reaction need be given. When the acid amides are treated with bromine and sodium hydroxide they lose the CO-group in the form of CO_2 and pass into the next lower primary amines, which, by further treatment with the same reagents, become converted into the nitrile of a carboxylic acid containing an atom less of carbon, and its amide is still capable of a like transformation. By this method the higher, more easily obtained, normal fatty acids can be changed into lower acids:

$$\underset{\text{Myristamide.}}{C_{13}H_{27}CONH_2} \longrightarrow \underset{\text{Tridecylamine.}}{C_{13}H_{27}NH_2} \longrightarrow \underset{\text{Tridecyl Nitrile.}}{C_{12}H_{25}CN} \longrightarrow \underset{\text{Tridecylamide.}}{C_{12}H_{25}CONH}$$

3. Action of iodine on silver salts: silver acetate yields, in addition to CO_2, the acetic methyl ester; silver capronate yields CO_2 and caproic amyl ester (B. **25**, R. 581; **26**, R. 237):

$$2CH_3CO_2Ag + I_2 = CH_3CO_2CH_3 + CO_2 + 2AgI.$$

4. Bromo-valeric acid, obtained from the fatty acid, gives up HBr to diethyl aniline or quinoline, becoming changed to ethyl acrylic acid. This olefine monocarboxylic acid yields, on oxidation, propionic acid (C. 1899, I. 778):

$$\underset{\text{Valeric Acid.}}{CH_3CH_2.CH_2CH_2.COOH} \longrightarrow \underset{\text{Ethyl Acrylic Acid.}}{CH_3CH_2.CH{=}CHCOOH} \longrightarrow \underset{\text{Propionic Acid.}}{CH_3.CH_2.COOH.}$$

5. α-Bromopelargonic acid, from the simple acid, when boiled with aqueous potassium hydroxide, yields α-hydroxypelargonic acid, which gives octyl aldehyde on being heated to 260°:

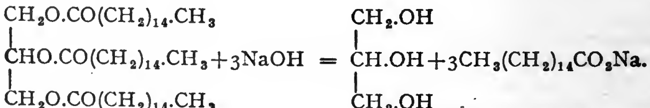
$$CH_3[CH_2]_7CH_2COOH \longrightarrow CH_3[CH_2]_7CHBrCOOH \longrightarrow$$
$$CH_3[CH_2]_7CH(OH)COOH \longrightarrow CH_3[CH_2]_7CHO.$$

TECHNICAL APPLICATION OF THE FATS AND OILS

Animal fats, especially mutton and beef-tallow, the nature of which was made clear by the classic researches of *Chevreul* in the beginning of last century, consist mainly of a mixture of *glycerol esters* of *palmitic, stearic,* and *oleic acids,* which are commonly called palmitin, stearin, and olein. They have been used in the preparation of *artificial butter* (margarine), in the manufacture of *stearin candles, soaps,* and *plasters* from the acid esters contained in them, and for the isolation of glycerol, which is used in part as such and in part in the form of *nitroglycerine.* Palm oil, coconut oil, and olive oil are also used as raw material.

The so-called *stearin* of candles consists of a mixture of stearic and palmitic acids. For its preparation, beef-tallow and suet, both solid fats, are saponified with calcium hydroxide or sulphuric acid, with superheated steam, or by the action of ferments present in some seeds, such as castor-oil beans (B. **37**, 1436). The acids which separate are distilled with superheated steam. The yellow, semi-solid distillate, a mixture of stearic, palmitic, and oleic acids, is freed from the liquid oleic acid by pressing it between warm plates. The residual, solid mass is then melted together with some wax or paraffin, to prevent crystallization occurring when the mass is cold, and moulded into candles.

When the fats are saponified by potassium or sodium hydroxide, salts of the fatty acids—*soaps*—are produced, *e.g.* sodium palmitate, according to the equation:



$$\begin{array}{l}CH_2O.CO(CH_2)_{14}.CH_3\\ |\\ CHO.CO(CH_2)_{14}.CH_3\\ |\\ CH_2O.CO(CH_2)_{14}.CH_3\end{array} + 3NaOH = \begin{array}{l}CH_2.OH\\ |\\ CH.OH\\ |\\ CH_2.OH\end{array} + 3CH_3(CH_2)_{14}CO_2Na.$$

Palmitin. Glycerol + Sodium Palmitate.

The sodium salts are solids and hard, whilst those of potassium are soft. Sodium chloride will convert potassium soaps into sodium soaps. In small quantities of water these salts of the alkalis dissolve completely, but with an excess of water they suffer decomposition, some alkali and fatty acid being liberated. This is the cause of the emulsifying action of soap, whereby it is enabled to take up fatty materials, and so exercise its detergent action (B. 29, 1328). The other metallic salts of the fatty acids are sparingly soluble or insoluble in water, but generally dissolve in alcohol. The lead salts, formed directly by boiling fats with litharge and water, constitute the so-called *lead plaster*.

The natural fats almost invariably contain several fatty acids. To separate them, the acids are set free from their alkali salts by means of hydrochloric acid and then fractionally crystallized from alcohol. The higher, less soluble acids separate out first. The separation is more complete if the acids be fractionally precipitated. The free acids are dissolved in alcohol, saturated with ammonium hydroxide, and an alcoholic solution of magnesium acetate added. The magnesium salt of the higher acid will separate out first; this is then filtered off and the solution again precipitated with magnesium acetate. The acids obtained from the several fractions are subjected anew to the same treatment, until, by further fractionation, the melting point of the acid remains constant—an indication of purity. The melting point of a mixture of two fatty acids is usually lower than the melting points of both acids (the same is the case with alloys of the metals).

Lanoline, or *wool fat*, is used in medicine.

DERIVATIVES OF THE FATTY ACIDS

I. ESTERS OF THE FATTY ACIDS

The esters of organic acids resemble those of the mineral acids in all respects (p. 130), and are prepared by analogous methods.

Methods of Formation.—(1) By direct action of acids and alcohols, whereby water is formed at the same time:

$$C_2H_5.OH + C_2H_3O.OH = C_2H_5.O.C_2H_3O + H_2O.$$

This reaction, as already stated, only takes place slowly (p. 131); heat hastens it, but it is never complete. A detailed investigation into the formation of esters, which is of importance to the study of chemical dynamics, was carried out by *Berthelot*.

If equivalent quantities of alcohol and acid be mixed, after a certain time a state of equilibrium will prevail between alcohol, acid, ester, and water; if any further quantity of ester were formed it would be hydrolyzed back to alcohol and acid by the water. In the case of acetic acid and ethyl alcohol, for example, this point is reached when about two-thirds of the acid has been esterified. If, however, an excess of alcohol is added to the mixture, the point of equilibrium is shifted in the direction of increased ester formation, so that a mixture of one equivalent of acetic acid and eight equivalents of alcohol is only in equilibrium when 0·945 equivalent of ester have been formed. The course of such a reaction is directed by the *Law of Mass Action*, developed by *Guldberg* and *Waage* (1867), and by *van 't Hoff*, which enunciates that the reaction between two bodies is dependent, not only on their affinity constant, but also on their relative concentrations, so that reactions between substances of slight affinity but in high concentration may balance those of high affinity and little concentration. Equilibrium is defined by the equation:

$$C_1^{n_1}.C_2^{n_2}.\kappa = C'^{m_1}_1.C'^{m_2}_2.\kappa' \quad \text{or} \quad \frac{C_1^{n_1}.C_2^{n_2}}{C'^{m_1}_1.C'^{m_2}_2} = \frac{\kappa'}{\kappa} = K$$

where n_1 and n_2 represent the two molecules resulting from the reacting molecules m_1 and m_2, C_1, C_2, C'_1, C'_2 their relative concentrations, κ the affinity constant for n_1 and n_2 in the direction of reaction towards m_1 and m_2, and κ' the affinity constant of m_1 and m_2 towards n_1 and n_2. K is the constant for the mixture of all four compounds—alcohol, acetic acid, ester, and water. A collection of the various calculations applicable to such reactions is found in B. **17,** 2177; **19,** 1700. *Menschutkin* has investigated the ester formation of various homologous series of acids and alcohols (A. **195,** 334; **197,** 193; B. **15,** 1445, 1572; **21,** R. 41). It was found that the normal primary alcohols possessed the same velocity of reaction except methyl alcohol, which showed an increased value. The secondary alcohols entered more slowly into combination, and the tertiary slowest of all. Among the acids, formic acid exceeded that of acetic acid, and this in turn the homologues, in the initial velocity of esterification; apart from this they showed a diminishing velocity with increasing molecular complexity. Acids in which a primary alkyl group was contiguous to a carboxylic group, had a greater velocity than when a secondary alkyl group occupied that position, which in turn was greater than when a tertiary group was substituted.

It can be seen that the process of esterification is favoured, *i.e.* the position of equilibrium can be displaced in the direction of complete reaction, by the withdrawal of the ester as soon as it is formed, such as can occur if it is sufficiently volatile to be distilled off. Further, the velocity of reaction, *i.e.* the time taken to reach equilibrium, can be greatly accelerated by the addition of mineral acids, such as hydrochloric, sulphuric, or other strong acids, which act as *catalyzers*, as they do, for instance, in the inversion of sucrose, etc. (B. **39,** 711, etc.).

The above account indicates the working conditions for the preparation of esters. (*a*) A mixture of acid or its salt, alcohol and sulphuric acid is distilled. (*b*) Or, in the case of esters of slight volatility, the acid or its salt is dissolved in excess of alcohol, or the alcohol in the acid, and gaseous HCl is passed into the mixture; or else sulphuric acid is added, and the ester is thrown out by the addition of water. With many acids a very suitable esterifying agent is a dilute solution of hydrochloric or sulphuric acid in alcohol (B. **28,** 3201, 3215, 3252). In many cases it is advantageous to act on the carboxylic acid with an equivalent quantity of alcohol and an excess of sulphuric acid (C. 1905, I. 365). (See also Vol. II.: Esters of aromatic carboxylic acids.)

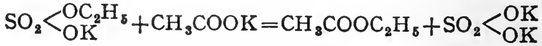
The following are noteworthy methods of formation:

(2) Double decomposition of the alkyl esters of mineral acids with salts of the organic acids:

(*a*) By the action of the alkylogens on salts of the acids, *e.g.* iodoalkyls and silver salts:

$$C_2H_5I + CH_3COOAg = CH_3COOC_2H_5 + AgI.$$

(*b*) By the dry distillation of a mixture of the alkali salts of the fatty acids and salts of alkyl sulphates:



$$SO_2{<}^{OC_2H_5}_{OK} + CH_3COOK = CH_3COOC_2H_5 + SO_2{<}^{OK}_{OK}$$

(*c*) The methyl ester can be prepared from the sodium or potassium salt of the acid and dimethyl sulphate (B. **37,** 4144; A. **340,** 244):

$$2CH_3COOK + (CH_3)_2SO_4 = 2CH_3COOCH_3 + K_2SO_4.$$

(3*a*) By the action of *acid chlorides* (p. 269) or *acid anhydrides* (p. 271) on the alcohols or alcoholates; and by the action of anhydrides or acid chlorides on alcohols in the presence of tertiary bases such as pyridine (C. 1901, II. 1223):

$$C_2H_5OH + CH_3COCl = CH_3COOC_2H_5 + HCl.$$
$$C_2H_5OH + (CH_3CO)_2O = CH_3COOC_2H_5 + CH_3COOH.$$

In these reactions, it is sometimes more convenient to employ instead of the simple alcoholates, the halogen magnesium alcoholates ROMgX (prepared from alkyl magnesium halides and alcohols), on account of their solubility in ether (B. **39,** 1736).

(3*b*) By the action of acid chlorides on alkyl ethers in the presence of zinc chloride, *e.g.* ethyl ether and acetyl chloride yield chloromethane and ethyl acetate (C. 1907, I. 1265).

(4) Acid nitriles are converted directly into esters when they are dissolved in alcohol and are subjected to the passage of HCl gas, or are heated with a little dilute acid (p. 280).

(5) Electro-syntheses of monocarboxylic esters (p. 253).

Properties.—Usually, the esters of fatty acids are volatile, neutral liquids, soluble in alcohol and ether, but generally insoluble in water. Many of them possess an agreeable fruity odour, and are prepared in large quantities, as they find extended application as *artificial fruit essences.* Nearly all fruit-odours may be made by mixing the different esters. The esters of the higher fatty acids occur in the natural varieties of wax.

Consult B. **14,** 1274; A. **218,** 337; **220,** 290, 319; **223,** 247, upon the boiling points, the specific gravities and specific volumes of the fatty acid esters.

Reactions.—(1) When the esters are heated with water they undergo a partial decomposition into alcohol and acid. This decomposition (*saponification*) (p. 251) is more rapid and complete on heating with alkalis in alcoholic solution:

$$C_2H_3O.OC_2H_5+KOH=C_2H_3O.OK+C_2H_5.OH.$$

Consult A. **228,** 257, and **232,** 103; B. **20,** 1634, upon the velocity of saponification by various bases.

(2) Ammonia changes the esters into amides (p. 275):

$$C_2H_3O.OC_2H_5+NH_3=C_2H_3O.NH_2+C_2H_5.OH.$$

(3) The halogen acids convert the esters into acids and haloid-esters (A. **211,** 178):

$$C_2H_3O.O.C_2H_5+HI=C_2H_3O.OH+C_2H_5I.$$

(4) By the action of PCl_5 the substituted hydroxyl oxygen is replaced by chlorine, and both radicals are converted into halogen derivatives. Compare *oxalic ester* for the course of this reaction:

$$C_2H_3O.O.C_2H_5+PCl_5=C_2H_3O.Cl+C_2H_5Cl+POCl_3.$$

(5) The esters, containing alcohol radicals with high molecular weight, break down, when heated or distilled under pressure, into fatty acids and *olefines* (p. 83).

(6) Esters are reduced by sodium in absolute alcohol solution to the alcohol corresponding with the acid radical (C. 1905, II. 1700):

$$CH_3(CH_2)_4COOC_2H_3 \longrightarrow CH_3[CH_2]_4CH_2OH.$$

Esters of Acetic Acid.—The *Methyl Ester, Methyl Acetate,* $C_2H_3O_2.CH_3$, b.p. 57·5°, D_0=0·9577, occurs in crude wood-spirit. When chlorine acts on it the alcohol radical is first substituted: $C_2H_3O_2.CH_2Cl$, b.p. 150°; $C_2H_3O_2.CHCl_2$, b.p. 148°.

The **Ethyl Ester,** *Ethyl Acetate, Acetic Ether,* $C_2H_3O_2.C_2H_5$, b.p. 77°, m.p. −82°, D_0=0·9238, is technically prepared from acetic acid, alcohol, and sulphuric acid, and constitutes the officinal *Æther aceticus.* It is the parent substance for the production of *acetoacetic ester,* $CH_3.CO.CH_2.CO_2.C_2H_5$, a step in the formation of *antipyrine.* Chlorine produces substitution compounds of the alcohol radicals.

n-*Propyl Ester,* b.p. 101°; *Isopropyl Ester,* b.p. 91°; n-*Butyl Ester,* b.p. 124°; *Isobutyl Ester,* b.p. 116°; sec.-*Butyl Ester,* b.p. 111°; tert.-*Butyl Ester,* b.p. 96°; n-*Amyl Ester,* b.p. 148°; n-*Propyl Methyl Carbinol Acetate,* $(CH_3CH_2CH_2)CH_3.CHO.COCH_3$, b.p. 133°; *Isopropyl Methyl Carbinol Acetate,* b.p. 125°, is decomposed into amylene and acetic acid at 200°.

Isobutyl Carbinol Acetate; acetic ester of fermentation amyl alcohol, b.p. 140°, in dilute alcoholic solution posessses the odour of pears and is employed as "pear oil." It is used also in the varnish industry.

Acetic n *Hexyl Ester*, b.p. 169–170°, occurs in the oil of *Heracleum giganteum*, and possesses a fruit-like odour. *Acetic* n-*Octyl Ester*, b.p. 207°, is also present in the oil of *Heracleum giganteum*, and has the odour of oranges.

Allyl Ester, b.p. 98–100°.

For higher acetic esters, see A. **233**, 260.

Furthermore, the addition products of the *aldehydes* and acetic anhydride are the *acetic esters* (p. 195) of those glycols not capable of existing in a free condition. The aldehydes are probably the anhydrides of these bodies.

Later, in the presentation of the polyhydric alcohols their acetic esters will always be described, for by their saponification a clue can be obtained as to the number of hydroxyl groups present in the alcohol.

Esters of Propionic Acid.—The *Methyl Ester*, b.p. 79·5°; *Ethyl Ester*, b.p. 98·8°; n-*Propyl Ester*, b.p. 122°; *Isobutyl Ester*, b.p. 137°; *Isoamyl Ester*, b.p. 160°, has an odour like that of pine-apples (see A. **233**, 253).

Esters of n-Butyric Acid.—*Methyl ester*, b.p. 102·3°, has an odour like that of apples; *ethyl ester*, b.p. 120·9°, has a pine-apple-like odour, and is employed in the manufacture of artificial rum. Its alcoholic solution is the artificial *pine-apple oil*, n-*Propyl ester*, b.p. 143°; *Isopropyl Ester*, b.p. 128°; *Isobutyl Ester*, b.p. 157°; *Isoamyl Ester*, b.p. 178°, possesses an odour resembling that of pears; n-*Hexyl Ester*, b.p. 205; and n-*Octyl Ester*, b.p. 244°, are found in the oil obtained from various species of *Heracleum* (see above); *octyl ester* occurs in *Pastinaca sativa* (A. **163**, 193; **166**, 80; **233**, 272).

Esters of Isobutyric Acid.—*Methyl Isobutyric Ester*, b.p. 92·3°; *Ethyl Isobutyric Ester*, b.p. 110°; n-*propyl ester*, b.p. 135° (A. **218**, 334).

Esters of the Valeric Acids.—n-*Valeric Ethyl Ester*, b.p. 144° (A. **233**, 274); iso-*Valeric Ethyl Ester*, b.p. 135°; iso-*Valeric Isoamyl Ester*, b.p. 194°.

Methyl Ethyl Acetic Ethyl Ester, b.p. 133·5° (A. **195**, 120); *Trimethyl Acetic Ethyl Ester*, b.p. 118° (A. **173**, 372).

Esters of the Hexoic Acids.—n-*Ethyl Ester*, b.p. 167°; *Isobutyl Acetic Ethyl Ester*, b.p. 161°.

n-Heptoic Ethyl Ester, b.p. 187–188°; n-*Octoic Ethyl Ester*, b.p. 207–208° (A. **233**, 282); n-*Nonoic Ethyl Ester*, b.p. 227–228°; n-*Capric Ethyl Ester*, b.p. 243–245°; n-*Capric Isoamyl Ester*, b.p. 275–290° with decomposition, is the principal constituent of the fusel oil of wine.

Lauric Ethyl Ester, b.p. 269°; *Myristic Ethyl Ester*, m.p. 10–11°, b.p. 295°.

Spermaceti and the Waxes.

Some of the esters with high molecular weights occur already formed in spermaceti and the waxes. This fact has been noted in connection with the corresponding alcohols and acids. The waxes are distinguished from the fats in that they consist of esters of monohydric alcohols with high molecular weight, whereas the fats are the esters of the *trihydric* alcohol, *glycerol*. Spermaceti belongs to the wax variety.

Spermaceti, *Cetaceum*, occurs in the oil from peculiar cavities in the heads of whales (particularly *Physeter macrocephalus*), and upon standing and cooling it separates as a white crystalline mass, which can be purified by pressing and recrystallization from alcohol. It consists of **Palmitic Cetyl Ester**, $C_{16}H_{31}O_2.C_{16}H_{33}$, m.p. 40°, which crystallizes from hot alcohol in waxy, shining needles or leaflets. It volatilizes undecomposed in a vacuum. Distilled under pressure, it yields *hexadecylene* and *palmitic acid*. When boiled with alcoholic potassium hydroxide it gives palmitic acid and cetyl alcohol (p. 122).

Waxes.—Ordinary *beeswax*, m.p. 61–64°, is a mixture of cerotic acid, $C_{26}H_{52}O_2$ or $C_{27}H_{54}O_2$, with **Myricyl Palmitate,** $C_{16}H_{31}O_2.C_{30}H_{61}$. Boiling alcohol extracts the cerotic acid and the ester, *myricin*, remains (A. **224**, 225).

Consult A. **235**, 106, for other constituents of beeswax.

Carnaüba wax, m.p. 83°, occurs in the leaves of the carnuba tree, and contains free ceryl alcohol and various acid esters (A. **223**, 283).

Chinese Wax or *Insect Wax* is obtained by the *Coccus ceriferus*, Fabr., from the Chinese ash, *Fraxinus chinensis*. It consists mainly of *Ceryl Cerotate*, $C_{26}H_{51}O_2.C_{26}H_{53}$, m.p. 81°. It is decomposed into cerotic acid and ceryl alcohol by alcoholic potassium hydroxide.

2. ACID HALIDES, OR HALOID ANHYDRIDES OF THE FATTY ACIDS

The haloid anhydrides of the acids (or acid halides) are those derivatives which arise in the replacement of the hydroxyl of acids by halogens; they are the halogen compounds of the acid radicals. They have been termed haloid anhydrides, bcause they can be viewed as *mixed anhydrides* (p. 272) of the fatty acids and the halide acids, corresponding with the method of formation (1) of the acid chlorides.

Acid Chlorides.—(1) From fatty acids and hydrochloric acid, by means of P_2O_5:

$$CH_3.COOH+HCl \xrightarrow{P_2O_5} CH_3.COCl+H_2O.$$

(2) By the action of hydrochloric acid gas on a mixture of an acid nitrile and a carboxylic acid or an anhydride at 0°. The hydrochloride of the acid amide is produced at the same time (B. **29**, R. 87):

$$CH_3CN+CH_3COOH+2HCl=CH_3CONH_2.HCl+CH_3COCl.$$

(3) By the action of chlorine on aldehydes:

$$CH_3COH+Cl_2=CH_3COCl+HCl.$$

(4) A far more important method of formation consists in acting with phosphorus halides on the acids or their salts—just as the alkylogens are produced from the alcohols (p. 132):

$$(a)\quad CH_3COOH+PCl_5=CH_3COCl+POCl_3+HCl$$
$$(b)\quad 3CH_3COOH+PCl_3=3CH_3COCl+H_3PO_3$$
$$(c)\quad 2CH_3COONa+POCl_3=2CH_3COCl+NaPO_3+NaCl.$$

Should there be an excess of the salt in the latter case, the acid will also act on it, producing acid anhydrides (p. 271). The action, particularly upon the salts, is very violent.

(5) Carbon oxychloride (B. **17**, 1285; **21**, 1267) and thionyl chloride (C. 1901, II. 527) react similarly to the phosphorus chlorides on free acids and their salts; as well as *p*-toluene sulphochloride or sodium chlorosulphonate, $NaOSO_2Cl$, on the salts (C. 1901, II. 518; 1904, I. 65) when acid chlorides and anhydrides are formed:

$$C_2H_3O.OH+COCl_2=C_2H_3OCl+CO_2+HCl$$
$$CH_3COONa+NaOSO_2Cl=CH_3COCl+(NaO)_2SO_2.$$

(6) Acid chlorides are also produced by the interaction of phosgene and zinc alkyls (p. 252).

Historical.—*Liebig* and *Wöhler* obtained the first acid chloride in 1832, when they treated benzaldehyde, C_6H_5COH, with chlorine. It was *benzoyl chloride*, C_6H_5COCl, the chloride of the simplest aromatic acid—benzoic acid. In 1846, *Cahours* discovered the method of producing aromatic acid chlorides by the action of phosphorus pentachloride on monocarboxylic acids. *Acetyl chloride* was first prepared in 1851 by *Gerhardt* (A. **87,** 63) by treating sodium acetate with phosphorus oxychloride.

Acid Bromides.—(1) The phosphorus bromides act like the corresponding chlorides on the fatty acids or their salts. A mixture of amorphous phosphorus and bromine may be employed as a substitute for the bromide itself.

(2) An interesting method for preparing the bromides of brominated acetic acid consists in acting with air on certain bromide derivatives of ethylene, whereby oxygen is absorbed, and an intramolecular atomic rearrangement (p. 36) takes place (B. **13,** 1980; **21,** 3356, II. 702):

unsym.-Dibromethylene, $CH_2{=}CBr_2 \xrightarrow{O} CH_2Br.COBr$, Bromacetyl Bromide.

Tribromethylene, $CHBr{=}CBr_2 \xrightarrow{O} CHBr_2.COBr$, Dibromacetyl Bromide.

Acid Iodides.—Phosphorus iodide does not convert the acids into iodides of the acid radicals; this only occurs when the acid anhydrides are employed. They are also produced by the interaction of acid chlorides and calcium iodide.

Acid Fluorides.—*Acetyl Fluoride* is a gas with an odour resembling that of phosgene. It is formed in the action of AgF or AsF_3 on acetyl chloride. A better procedure consists in allowing acid chlorides to act on anhydrous zinc fluoride.

Propionyl Fluoride, $CH_3.CH_2.COF$, b.p. 44° (C. 1897, I. 1090).

Properties and Reactions.—The acid halides are sharp-smelling liquids, which fume in the air. They are heavier than water, and at ordinary temperatures (1) decompose, forming carboxylic acids and halogen acids. The more readily soluble the resulting acid is in water, the more energetic will the reaction be.

The acid chlorides act similarly on many other bodies. (2) They yield compound ethers, or esters, with the alcohols or alcoholates (p. 266). (3) With salts or acids they yield acid anhydrides (p. 271), and (4) with ammonia, the amides of the acids, etc. (p. 274). (5) Tertiary amines withdraw HCl from the acid chlorides, possibly with the intermediate formation of *ketones*, $R_2C{=}CO$, which undergo further change. Acetyl chloride yields dehydracetic acid, $C_8H_8O_4$ (*q.v.*); isobutyl chloride gives tetramethyl diketo-cyclo-butene $[(CH_3)_2C.CO]_2$ (Vol. II.) (B. **39,** 1631).

(6). Sodium amalgam, or better, sodium and oxalic acid (B. **2,** 98), will convert the acid chlorides into *aldehydes* and alcohols (p. 191), which can be further reduced to primary alcohols (p. 104). (7) They yield ketones and tertiary alcohols when treated with the zinc alkyls (pp. 217 and 105). (8) By the action of silver cyanide they pass into the *acid cyanides*, which are described as the nitriles of the α-ketone carboxylic acids. (9) Di- and poly-carboxylic acids, having the power of forming anhydrides, are converted into their anhydrides when treated with acid chlorides (especially acetyl chloride).

Acetyl Chloride, *Ethanoyl Chloride*, $CH_3.CO.Cl$, b.p. 55°, $D_0{=}1{\cdot}130$ is formed according to the general methods applied in the production of acid chlorides, and by carefully distilling a mixture of acetic acid (3 parts) and PCl_3 (2 parts). Or, by heating $POCl_3$ (2 molecules) with acetic acid (3 molecules), as long as HCl escapes, and then distilling (A. **175,** 378). The acetyl chloride is purified by a second distillation, this time over a little dry sodium acetate. It is a colourless, pungent-smelling liquid. Water decomposes it very energetically. For its reactions, consult the preceding paragraphs.

Acetyl chloride forms chlorinated acetic acids (p. 287) with chlorine. Compare acetyl acetone.

Acetyl Bromide, b.p. 81°. *Acetyl Iodide*, b.p. 108°. *Propionyl Chloride*, $CH_3.CH_2COCl$, b.p. 80°; *bromide*, b.p. 104°; *iodide*, b.p. 127°.

Butyryl Chloride, C_4H_7OCl, b.p. 101° (B. **34**, 4051). Aluminium chloride changes it to triethyl phloroglucinol (B. **27**, R. 507; n-*bromide*, b.p. 128°; n-*iodide*, b.p. 146°; *Isobutyryl Chloride*, $(CH_3)_2CH.COCl$, b.p. 92°, for reactions with tertiary amino bases, see p. 270; *bromide*, b.p. 116°.

Valeryl Chloride, b.p. 107°; *Isovaleryl Chloride*, C_5H_9OCl, b.p. 114·5°; *bromide*, b.p. 143°; *iodide*, b.p. 168°.

Trimethyl Acetic Chloride, $(CH_3)_3CCOCl$, b.p. 105–106°; n-*Caproyl Chloride*, $CH_3(CH_2)_4COCl$, b.p. 146°; *Diethyl Acetyl Chloride*, $(C_2H_5)_2CHCOCl$, b.p. 135°; *Dimethyl Ethyl Acetic Chloride*, $(CH_3)_2(C_2H_5)C.COCl$, b.p. 132°.

Consult B. **17**, 1378; **19**, 2982; **23**, 2384, for the chlorides of the higher fatty acids.

The boiling point of the normal acid chlorides shows an increase of 48° between each member of the series and its next but one higher member. This interval is made up of 28° between a chloride containing an even number of carbon atoms and the next higher member, which, of course, contains an odd number, and 20° between this and the next higher which possesses an even number of carbon atoms (C. 1899, I. 968).

With these acid chlorides or haloid anhydrides are connected the mixed anhydrides of a fatty acid with inorganic acids, such as nitric and nitrous acids, chromic acid, boric acid, arsenious acid.

Diacetyl Orthonitric Acid, $(CH_3COO)_2N(OH)_3$, b.p. 128°, $D_{15}=1{\cdot}197$, results when fuming nitric acid (D.=1·4) reacts with acetic anhydride, or glacial acetic acid with nitric acid. It is a colourless liquid, fuming in air, and decomposed by water into acetic and nitric acids. It possesses an oxidizing and nitrating action. Excess of acetic anhydride converts it into tetranitromethane, $C(NO_2)_4$ (B. **35**, 2526; **36**, 2225).

Acetyl Nitrate, $CH_3COO.NO_2$, b.p.$_{77}$ 22°, is prepared from N_2O_5 and acetic anhydride. It is a colourless mobile liquid, fuming in air, and explodes when rapidly heated. At 60° it evolves nitrous fumes and forms tetranitromethane. With alcohol it forms a mixture of acetic and nitric esters which acts as a strong nitrating mixture for benzene derivatives (C. 1907, I. 1025).

Acetyl Nitrite, $CH_3COO.NO$, is obtained from silver acetate and NOCl, and forms an easily decomposed golden-yellow liquid (C. 1904, II. 511).

Acetyl Chromate, $(CH_3COO)CrO_3H$, results from mixing CrO_3 and glacial acetic acid (B. **36**, 2215).

Triacetyl Borate, m.p. 121°, is obtained from B_2O_3 and acetic anhydride. Alcohols produce from it boric ester, whilst carboxylic acids give rise to other mixed boric anhydrides, such as *Tristearyl Borate*, $(C_{18}H_{35}O_2)B$, m.p. 71° (B. **36**, 2219).

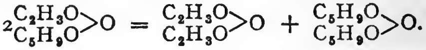
Acetyl Arsenite, m.p. 82°, b.p.$_{31}$ 165–170°, is formed from As_2O_3 and acetic anhydride (C. 1906, I. 21).

3. CARBOXYLIC ACID ANHYDRIDES, ACYL OXIDES

The acid anhydrides are the oxides of the acid radicals. In those of the monobasic acids two acid radicals are united by an oxygen atom; they are analogous to the oxides of the univalent alcohol radicals—the ethers.

The ***simple*** **anhydrides, those containing two** ***similar*** **radicals, can usually**

be distilled, whilst the *mixed* anhydrides, with two dissimilar radicals, decompose when heated, into two simple anhydrides:

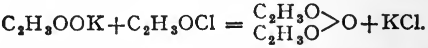


$$2\begin{matrix}C_2H_3O\\C_5H_9O\end{matrix}\!>\!O = \begin{matrix}C_2H_3O\\C_2H_3O\end{matrix}\!>\!O + \begin{matrix}C_5H_9O\\C_5H_9O\end{matrix}\!>\!O.$$

Hence they cannot be separated from the product of the reaction by distillation, but have to be dissolved out with ether.

Formyl acetyl oxide, $HCO.O.COCH_3$, however, can be volatilized unchanged under reduced pressure.

Methods of Formation.—(1*a*) The chlorides of the acid radical are allowed to act on anhydrous salts, such as the alkali salts of the acids:



$$C_2H_3OOK+C_2H_3OCl = \begin{matrix}C_2H_3O\\C_2H_3O\end{matrix}\!>\!O+KCl.$$

(1*b*) The anhydrides of the higher fatty acids can also be produced by the action of acetyl chloride (B. **10**, 1881) (A. **226**, 12; C. 1899, I. 1070) on the free acids; in the latter case mixed anhydrides are also obtained. The action of the chloride on the free carboxylic acids is assisted by the presence of a tertiary base, such as pyridine, quinoline, or triethylamine, which takes up the hydrochloric acid set free during reaction (B. **34**, 2070; C. 1901, II. 543).

(2) Phosphorus oxychloride (1 molecule) acts on the dry alkali salts of the acids (4 molecules). The acid chloride, which is also produced, reacts immediately on its formation with the excess of salt:

I Phase: $2C_2H_3O.OK+POCl_3=2C_2H_3O.Cl+KPO_3+KCl$
II Phase: $C_2H_3O.OK+C_2H_3O.Cl=(C_2H_3O)_2O+KCl.$

(3) Phosgene, $COCl_2$, acts like $POCl_3$. In this reaction acid chlorides are also produced (p. 269).

(4) A direct conversion of the acid chlorides into the corresponding anhydrides may be effected by reacting with the former on anyhdrous oxalic acid (A. **226**, 14):

$$2C_2H_3OCl+C_2O_4H_2=(C_2H_3O)_2O+2HCl+CO_2+CO.$$

Historical.—Charles *Gerhardt* (1851) discovered the acid anhydrides. The important bearing of this discovery upon the *type theory* has already been alluded to in the Introduction.

Properties and Reactions.—The acid anhydrides are liquids or solids of neutral reaction, and are soluble in ether. Their boiling points are *higher* than those of the corresponding acids. (1) Water decomposes them into their constituent acids:

$$(CH_3CO)_2O+H_2O=2CH_3COOH.$$

(2) With alcohols they yield the esters (C. 1906, II. 1043):

$$(CH_3CO)_2O+C_2H_5OH=CH_3COOC_2H_5+CH_3COOH.$$

(3) Ammonia and primary and secondary amines convert them into amides and ammonium salts:

$$(CH_3CO)_2O+2NH_3=CH_3CONH_2+CH_3COONH_4.$$

(4) Heated with hydrochloric acid, hydrobromic and hydriodic acids, they decompose into an acid halide and free acid:

$$(CH_3CO)_2O+HCl=CH_3COCl+CH_3COOH.$$

(5) Chlorine splits them up into acid chlorides and chlorinated acids:

$$(CH_3CO)_2O + Cl_2 = CH_3COCl + ClCH_2COOH.$$

(6) Sodium amalgam changes the anhydrides to aldehydes and primary alcohols.

(7) Aldehydes and acid anhydrides combine to form esters.

Simple Anhydrides.—Acetic Anhydride [Ethane Acid Anhydride], $(C_2H_3O)_2O$, b.p. 137°, $D_0 = 1{\cdot}073$, is a mobile, pungent-smelling liquid.

It is prepared by distillation of a mixture of anhydrous sodium acetate (three parts) and $POCl_3$ (one part); or of the product of reaction of equal parts of acetyl chloride and sodium acetate. The anhydride can then be dissolved undecomposed in about ten parts of cold water, and in this form may be used for *acetylating amino-bases* in aqueous solution (C. 1905, II. 466; 1906, II. 1042).

Propionic Anhydride, $(C_3H_5)_2O$, b.p. 168°. *Butyric Anhydride*, b.p. 199°. *Isobutyric Anhydride*, b.p. 181·5°. n-*Caproic Anhydride*, b.p. 242°, with decomposition. *Œnanthic Anhydride*, m.p. 17°, b.p.$_{15}$ 164°. n-*Oetylic Anhydride*, m.p. −1°, b.p.$_{15}$ 186°. *Pelargonic Anhydride*, m.p. 16°, b.p.$_{15}$ 207°. *Palmitic Anhydride*, m.p. 64°. *Stearic Anhydride*, m.p. 71–77° (C. 1899, I. 1070; B. **33**, 3576).

MIXED ANHYDRIDES

Acetyl Formyl Oxide, $HCO.O.COCH_3$, b.p.$_{18}$ 29°, is prepared by mixing formic acid and acetic anhydride in the cold, a reaction which can be employed for the formation of higher homologues. At ordinary pressures it boils with partial decomposition. Quinoline liberates CO, and alcohols form formyl esters (*Béhal*, C. 1900, II. 750). For other mixed anhydrides, see B. **34**, 168.

4. ACID PEROXIDES

The peroxides of the acid radicals are prepared by heating the chlorides or anhydrides in ethereal solution with barium peroxide (*Brodie*, Pogg. Ann., **121**, 382), or by the action of the ice-cold chloride on sodium peroxide hydrate (B. **33**, 1043). Also, by the addition of pure hydrogen peroxide to acetic anhydrides (A. **298**, 288):

$$(C_2H_3O)_2O + BaO_2 = (C_2H_3O)_2O_2 + BaO.$$

Diacetyl Peroxide, m.p. 30°, b.p.$_{21}$ 63°, possesses a sharp odour like ozone. It is insoluble in water, but easily soluble in alcohol and ether. It is very unstable and acts as a strong oxidizing agent, liberating iodine from a KI solution, and decolorizing a solution of indigo. Sunlight decomposes it, and it explodes violently on heating. Water hydrolyzes it into acetic acid and *Acetyl Peroxide*, CH_3COOOH, which has not been isolated. Barium hydroxide solution decomposes it, forming barium acetate and barium peroxide. *Propionic Peroxide*, $(C_3H_5O)_2O_2$, is obtained from propionic anhydride and BaO_2: it is a liquid (C. 1903, I. 958).

5. THIO-ACIDS

By the replacement of oxygen in a monocarboxylic acid by sulphur three results are possible:

1. R′.CO.SH. Thio-acids, Carbothiolic acids.
2. R′.CS.OH Thionic Acids. Carbolthionic acids (comp. Thiamides)
3. R′.CS.SH Dithionic Acids, Carbithionic acids.

a. **Thio-acids.**—The first thio-acid—*thiacetic acid*, $CH_3.COSH$,—was obtained by *Kekulé* (A. **90**, 309) when phosphorus pentasulphide acted on acetic acid. In its preparation it is advisable to mix the P_2S_5 with half its weight of coarse fragments of glass:

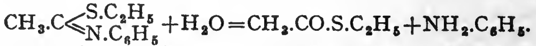
$$5C_2H_3O.OH + P_2S_5 = 5C_2H_3O.SH + P_2O_5.$$

The *thio-anhydrides* arise in the same manner by the action of phosphorus sulphide on the acid anhydrides. The thio-acids are produced by the action of acid chlorides on potassium hydrogen sulphide, or from phenyl esters and NaSH in alcoholic solution (C. 1903, I. 816). The disagreeably-smelling thio-acids correspond with the thio-alcohols or mercaptans (p. 142), their *sulphanhydrides* with the acid anhydrides and the simple sulphides, and their *disulphides* with the peroxides and alkyl disulphides:

CH_3CH_2SH Ethyl Mercaptan.	CH_3COSH Thiacetic Acid.	CH_3CO_2H Acetic Acid.
$(CH_3CH_2)_2S$ Ethyl Sulphide.	$(CH_3CO)_2S$ Thiacetic Anhydride.	$(CH_3CO)_2O$ Acetic Anhydride.
$(CH_3CH_2)_2S_2$ Ethyl Disulphide.	$(CH_3CO)_2S_2$ Acetyl Disulphide.	$(CH_3CO)_2O_2$ Acetyl Peroxide.

The *esters* are obtained when the alkylogens react with the salts of the thio-acids, and the acid chlorides with the mercaptans or mercaptides.

They also appear in the decomposition of alkyl isothioacetanilides with dilute hydrochloric acid:



$$CH_3.C\lessdot\begin{matrix}S.C_2H_5\\N.C_6H_5\end{matrix}+H_2O=CH_3.CO.S.C_2H_5+NH_2.C_6H_5.$$

Ethyl Isothioacetanilide. Thioacetic Ester. Aniline.

Concentrated potassium hydroxide decomposes the esters into fatty acids and mercaptans.

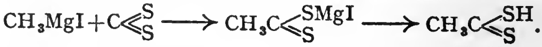
Thiacetic Acid, *Methyl Carbothiolic Acid*, CH_3COSH, b.p. 93°, $D_{10}=1{\cdot}074$, is a colourless liquid. Its odour resembles those of acetic acid and hydrogen sulphide. It dissolves with difficulty in water, but readily in alcohol and in ether. This acid has been recommended as a very convenient substitute for hydrogen sulphide in analytical operations (C. 1901, I. 1148), and is a suitable reagent for acetylating amines (B. **35**, 110). The *lead salt*, $(C_2H_3O.S)_2Pb$, crystallizes in minute needles, and readily decomposes with the formation of lead sulphide (C. 1897, I. 1090; II. 770). *Ethyl ester*, $C_2H_3O.S.C_2H_5$, b.p. 115°.

When thiacetic acid is heated with zinc chloride, there is formed *Tetraethenyl Hexasulphide*, $(CH_3C)_4S_6$, m.p. 224° (B, **36**, 204). On the formation of *Thiopropionic Acid, Ethyl Carbothiolic Acid*, C_2H_5COSH, from ethyl magnesium bromide and carbon oxysulphide, see B. **36**, 1009.

Acetyl Sulphide, $(C_2H_3O)_2S$, b.p. 157°, is a heavy, yellow oil, insoluble in water. Water gradually decomposes it into acetic and thiacetic acids (B. **24**, 3548, 4251).

Acetyl Disulphide, $(C_2H_3O)_2S_2$, is formed when acetyl chloride acts on potassium disulphide, or iodine on the salts of the thio-acid.

b. **Dithionic Acids.**—Just as carboxylic acids result from the treatment of acetyl magnesium halides with CO_2, so the doubly sulphur-substituted carboxylic acids, dithionic acids, are prepared by the action of CS_2 on the alkyl magnesium halides:



$$CH_3MgI+C\lessdot\begin{matrix}S\\S\end{matrix}\longrightarrow CH_3C\lessdot\begin{matrix}SMgI\\S\end{matrix}\longrightarrow CH_3C\lessdot\begin{matrix}SH\\S\end{matrix}.$$

They are reddish-yellow oils, of an offensive odour, which can be distilled without decomposition. They are strong acids, easily oxidized in the air to solid, stable, yellow *disulphides*, RCSS.SCSR.

Methyl Dithionic Acid, CH_3CS_2H, b.p.$_{15}$ 37°, $D_{20}=1{\cdot}24$, is prepared from methyl magnesium iodide and CS_2. It is a reddish-yellow oil, of an exceedingly penetrating and repulsive odour; it dissolves with difficulty in water, but easily in organic solvents. *Ethyl Dithionic acid*, $C_2H_5CS_2H$, b.p.$_{17}$ 48°. *Propyl Dithionic acid*, b.p.$_{12}$ 59°. *Isobutyl Dithionic acid*, b.p.$_{33}$ 84°. *Isoamyl Dithionic acid*, b.p.$_{10}$ 84°. (B. **40**, 1725.)

6. ACID AMIDES

These correspond with the amines of the alcohol radicals. The hydrogen of ammonia can be replaced by acid radicals, forming primary, secondary and tertiary acid amides:

$CH_3CO.NH_2$ Acetamide (primary).	$(CH_3CO)_2NH$ Diacetamide (secondary).	$(CH_3CO)_3N$ Triacetamide (tertiary).

The primary acid amides have as isomers, the imido-ethers (p. 281) of the formula $R'.C{<}^{OH}_{NH}$. To benzamide (Vol. II.) is ascribed, not only the formula $C_6H_5C{<}^{O}_{NH_2}$, but also $C_6H_5C{<}^{OH}_{NH}$, since the silver salt and iodoethane give benzimido-ethyl ether, $C_6H_5C{<}^{OC_2H_5}_{NH}$. The sodium salt is the only one which, on reacting with iodoethane, gives a benzamide in which the imide group is ethylated. This is taken as evidence that the metal is most probably united to the nitrogen atom according to the iso-imido formula. But as little can be deduced of the constitution of benzamide from a study of its salts as of that of acetoacetic ester, the nitroparaffins and similar compounds.

The hydrogen of primary and secondary amines, like that of ammonia, can be replaced by acid residues, giving rise to *mixed amides.*

General Methods of Formation.—(1) By the dry distillation of the ammonium salts of the acids of this series. A more abundant yield is obtained by merely heating the ammonium salts to about 230° (B. **15**, 979), (*Kündig*, 1858). (This method was first applied (1830) by *Dumas* to ammonium oxalate with the production of oxamide):

$$\underset{\text{Ammonium Acetate.}}{CH_3CO.ONH_4} = \underset{\text{Acetamide.}}{CH_3CONH_2} + H_2O.$$

A mixture of the sodium salts and ammonium chloride may be substituted for the ammonium salts. Consult B. **17**, 848, upon the velocity and limit of the amide production.

(2) By the action of ammonia, primary and secondary amines on the esters whereby *Liebig*, in 1834, obtained oxamide from oxalic ester:

$$CH_3CO.O.C_2H_5 + NH_3 = \underset{\text{Acetamide.}}{CH_3CO.NH_2} + C_2H_5.OH$$

$$CH_3CO.O.C_2H_5 + C_2H_5.NH_2 = \underset{\text{Ethyl Acetamide.}}{CH_3CONHC_2H_5} + C_2H_5.OH.$$

This reaction takes place in the cold, particularly in the case of water-soluble esters; or the ester may be heated with an aqueous or alcoholic solution of ammonia.

It is one of the so-called reversible reactions, inasmuch as the action of alcohols on acid amides again produces esters and ammonia (B. **22**, 24).

(3) By the action (*a*) of *acid halides*, (*b*) of *acid anhydrides* on ammonia, primary and secondary alkylamines. This was the method which *Liebig* and *Wöhler* first used in 1832 to prepare benzamide from benzoyl chloride.

(3*a*)

$$CH_3COCl + 2NH_3 = \underset{\text{Acetamide.}}{CH_3CONH_2} + NH_4Cl$$

$$CH_3COCl + 2NH_2C_2H_5 = \underset{\text{Ethyl Acetamide.}}{CH_3CONH.C_2H_5} + N(C_2H_5)H_3Cl$$

$$CH_3COCl + 2NH(C_2H_5)_2 = \underset{\text{Diethyl Acetamide.}}{CH_3CON(C_2H_5)_2} + N(C_2H_5)_2H_2Cl.$$

This method is especially well adapted for obtaining the amides of the higher fatty acids (B. **15**, 1728):

(3*b*)

$$(CH_3CO)_2O + 2NH_3 = CH_3CONH_2 + CH_3.CO_2NH_4$$

$$(CH_3CO)_2O + 2NH_2C_2H_5 = CH_3CONHC_2H_5 + CH_3CO_2NH_3C_2H_5.$$

(4) By the addition of one molecule of water to the nitriles of the acids (p. 278):

$$\underset{\text{Acetonitrile.}}{CH_3CN}+H_2O\ (180°)=\underset{\text{Acetamide.}}{CH_3CONH_2}.$$

This addition of water frequently occurs in the cold by the action of concentrated hydrochloric acid, or by mixing the nitrile with glacial acetic acid and concentrated sulphuric acid (B. **10**, 1061). Hydrogen peroxide in alkaline solution also converts the nitriles, with liberation of oxygen, into amides (B. **18**, 355). For the action of hydrochloric acid on a mixture of nitrile and fatty acid see (2), formation of acid chlorides.

(5) By the distillation of the fatty acids with potassium thiocyanate:

$$2C_2H_3O.OH+KSNC=C_2H_3O.NH_2+C_2H_3O.OK+COS.$$

Simply heating the mixture is more practical (B. **15**, 978; **16**, 2291). In making acetamide, glacial acetic acid and ammonium thiocyanate are heated together for several days. By this reaction the aromatic acids yield nitriles.

(6) By the interaction of fatty acids and *carbylamines* (p. 247):

$$2CH_3COOH+C{:}N.CH_3=\underset{\text{Methyl Formamide.}}{HCONHCH_3}+(CH_3CO)_2O.$$

(7) By the action of the fatty acids on *isocyanic acid esters* (*q.v.*):

$$CH_3COOH+CON.C_2H_5=CH_3.CONHC_2H_5+CO_2.$$

Secondary and **tertiary amides** are obtained (1) by heating primary acid amides (B. **23**, 2394), alkyl cyanides or nitriles with acids, or acid anhydrides, to 200°.

$$CH_3CONH_2+(CH_3CO)_2O=(CH_3CO)_2NH+CH_3COOH$$
$$CH_3CN+CH_3COOH=\underset{\text{Diacetamide.}}{(CH_3CO)_2NH}$$
$$CH_3CN+(CH_3CO)_2O=\underset{\text{Triacetamide.}}{(CH_3CO)_3N}.$$

Diacetamide is also prepared by the action of acetyl chloride on acetamide in solution in benzene (C. 1901, I. 678).

(2) The secondary amides can also be prepared by heating primary amides with dry hydrogen chloride:

$$2C_2H_3ONH_2+HCl=\underset{\text{Diacetamide.}}{(C_2H_3O)_2NH}+NH_4Cl.$$

(3) Mixed amides are further produced by the action of esters of isocyanic acid on acid anhydrides:

$$(C_2H_3O)_2O+CO{:}N.C_2H_5=\underset{\text{Ethyl Diacetamide.}}{(C_2H_3O)_2N.C_2H_5}+CO_2.$$

Properties and Reactions.—The amides of the fatty acids are usually solid, crystalline bodies, soluble in both alcohol and ether. The lower members are also soluble in water, and can be distilled without decomposition. As they contain the basic amido-group they are able to unite directly with acids, forming salt-like derivatives, *e.g.* $C_2H_3ONH_2.HNO_3$ and $(CH_3CONH_2)_2.HCl$, but these are not very stable, because the basic character of the amido-group has become greatly weakened by the acid radical. Furthermore, the acid radical imparts to the NH_2-group the power of exchanging a hydrogen atom for metals, such as mercury or sodium (B. **23**, 3037; C. 1902, II. 787), forming metallic derivatives, *e.g.* $(CH_3.CO.NH)_2.Hg$—mercury acetamide, analogous to the isocyanates (from isocyanic acid, HN:CO), and the salts of the imides of dibasic acids.

The union of the amido-group with the CO-group of the acid radical is very feeble in comparison with its union with the alkyls in the amines. The acid amides, therefore, readily absorb water and pass into ammonium salts, or acids and ammonia. (1) Heating with water effects this, although it is more easily accomplished by boiling with alkalis or acids. This is a reaction which is not infrequently termed *saponification* (p. 251), though *hydrolysis* is, perhaps, preferable.

$$CH_3CO.NH_2+H_2O=CH_3CO.OH+NH_3.$$

(2) Nitrous acid decomposes the primary amides similarly to the primary amines (p. 163):

$$C_2H_3O.NH_2+HNO_2=C_2H_3O.OH+N_2+H_2O.$$

Acid amides, which saponify with difficulty, may be dissolved in sulphuric acid, to which sodium nitrite is added in the cold (B. **28**, 2783).

(3) Bromine in alkaline solution changes the primary amides to bromamides (B. **15**, 407 and 752):

$$C_2H_3O.NH_2+Br_2=C_2H_3O.NHBr+HBr,$$

which then form amines (p. 159). (4) On heating with phosphorus pentoxide or chloride, they part with one molecule of water and become converted into nitriles (cyanides of the alcohol radicals):

$$CH_3.CO.NH_2=CH_3.CN+H_2O.$$

In this action a replacement of an oxygen atom by two chlorine atoms takes place; the resulting chlorides, like $CH_3.CCl_2.NH_2$, then lose, upon further heating, two molecules of HCl with the formation of nitriles.

Formamide, $H.CONH_2$. See p. 238.

Acetamide [Ethanamide], $CH_3CO.NH_2$, m.p. 82°, b.p. 222°, crystallizes in long needles. It dissolves with ease in water and alcohol. In explaining the methods of producing the amides, and in illustrating their behaviour, acetamide was presented as the example. *Dumas, Leblanc,* and *Malaguti* first prepared it in 1847, by allowing ammonia to act on acetic ester. For the preparation of acetamide from ammonium acetate, see C. 1906, I. 1089.

Acetomethylamide, $CH_3.CONHCH_3$, m.p. 28°, b.p. 206°; *Acetodimethylamide*, $CH_3.CO.N(CH_3)_2$, b.p. 165·5°; *Acetethylamide*, b.p. 205°; *Acetodiethylamide*, b.p. 185–186°. *Methylene Diacetamide*, $CH_2(NHCOCH_3)_2$, m.p. 196°, b.p. 288° (B. **25**, 310). *Chloralacetamide*, $CCl_3CH(OH)NHCOCH_3$, m.p. 117° (B. **10**, 168). Acetamide and butyl chloral yield two isomeric compounds, m.p. 158° and 170° respectively (B. **25**, 1690).

Diacetamide, $(C_2H_3O)_2NH$, m.p. 77°; b.p. 222·5–223·5° is readily soluble in water. (Preparation, p. 276.)

Methyl Diacetamide, $(CH_3CO)_2N.CH_3$, b.p. 192°. *Ethyl Diacetamide*, b.p. 185–192°.

Triacetamide, $(C_2H_3O)_3N$, m.p. 78–79°. (Preparation, p. 276.)

Acetochloramide, $CH_3CONHCl$, m.p. 110°.

Acetobromamide, $CH_3CONHBr+H_2O$, forms large plates, and melts in an anhydrous condition at 108° (B. **15**, 410). The production of *acetochloramylamide* $CH_3CO.NClC_5N_{11}$, from hypochlorous acid and aceto-amylamide, and from acetic anhydride and chloramylamine in glacial acetic acid (B. **34**, 1613), is taken as a demonstration that in such compounds the halogen atom is joined to the nitrogen atom.

Higher homologous primary Acid Amides:

Propionamide, m.p. 75°, b.p. 210°.

n-*Butyramide*, m.p. 115°, b.p. 216°. *Isobutyramide*, m.p. 128°, b.p. 216–220°.

n-*Valeramide*, m.p. 114–116°.

Trimethyl Acetamide, m.p. 153–154°, b.p. 212°; n-*Capronamide*, m.p. 100°, b.p. 225°; *Methyl* n-*Propylacetamide*, m.p. 95°; *Methyl Isopropylacetamide*, m.p. 129°; *Isobutyl Acetamide*, m.p. 120°; *Diethyl Acetamide*, m.p. 105°, b.p. 230–235°; *Œnanthamide*, m.p. 95°, b.p. 250–258°; n-*Caprylamine*, m.p. 105–106°; *Pelargonamide*, m.p. 92–93°; n-*Caprinamide*, m.p. 98°.

Lauramide, m.p. 102°, b.p.$_{12·5}$ 199–200°; *Tridecylamide*, m.p. 98·5°; *Myristamide*, m.p. 102°, b.p.$_{12}$ 217°; *Palmitamide*, m.p. 106°, b.p.$_{12}$ 235–236°; *Stearamide*, m.p. 108·5–109°, b.p.$_{12}$ 250–251° (B. **15**, 977, 1729; **19**, 1433; **24**, 2781; **26**, 2840).

7. ACID HYDRAZIDES

The mono-acyl hydrazides (C. 1902, I. 21) are obtained by the interaction of hydrazine and the acid esters, whilst the sym.-diacyl hydrazides are prepared from hydrazine and the acid anhydrides (B. **34**, 187). The latter-named bodies can also be obtained by heating monoacyl hydrazines and treating the product with iodine. Sym.-diacetohydrazide, heated with acetic anhydride, yields triacetohydrazide and tetra-acetohydrazide (B. **32**, 796).

The mono-acyl hydrazides condense with aldehydes and ketones with the production of water. The sym.-diacyl hydrazines react with zinc chloride or phosphorus pentoxide to form dialkyl pyrrodiazoles; with alcoholic ammonia, yielding dialkyl pyrrodiazoles; and with phosphorus pentoxide, forming dialkyl thiodiazoles. (B. **32**. 797).

Acetohydrazine, $CH_3CONH.NH_2$, m.p. 62°. *Acetobenzalhydrazine*, $CH_3CO.-NH.N:CH.C_6H_5$, m.p. 134°; sym.-*Diacetohydrazine*, m.p. 138°; b.p.$_{15}$ 209°. *Triacetohydrazine*, b.p.$_{15}$ 181°, *Tetra-acetohydrazine*, m.p. 85°, b.p.$_{15}$ 141°.

8. ACID AZIDES

Although the acid azides show a great chemical similarity to the acid halides (p. 269), they are best examined together with the acid hydrazides, on account of their generic connections. They are formed by the action of monoacyl hydrazine hydrochlorides on alkali nitrites.

Propionyl Azide, $CH_3.CH_2.CON_3$, is a volatile colourless liquid, of pungent odour; with alcohol it forms ethyl urethane (C. 1902, I. 22).

9. THE FATTY ACID NITRILES OR ALKYL CYANIDES

These are compounds in which *one* carbon atom, combined with an alkyl group R′.C≡—a residue present in every fatty acid—replaces the three hydrogen atoms of ammonia, *e.g.* $CH_3C{\equiv}N$, acetonitrile. It is true that in the *nitrile bases* (tertiary amines and amides) the nitrogen atom is also joined with three valences to carbon, but three alkyl residues are in union with *three* different carbon atoms.

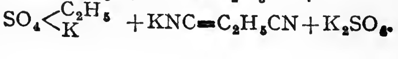
The acid nitriles are also called *alkyl cyanides*, because they may be considered as being *alkyl ethers* of hydrogen cyanide, H.C≡N.

Being intermediate steps in the synthesis of the *fatty acids* from the *alcohols*, these nitriles merit especial consideration.

The following general methods are employed for their preparation:

(1) *Nucleus-synthesis* from the alcohols: (*a*) by heating the alkylogens with potassium cyanide in alcoholic solution to 100°; (*b*) by the distillation of potassium alkyl sulphates with potassium cyanide (hence the name *alkyl cyanides*):

(1*a*) $C_2H_5I+KNC=C_2H_5CN+KI$

(1*b*) 
$SO_4{<}^{C_2H_5}_{K}+KNC=C_2H_5CN+K_2SO_4.$

Isocyanides (p. 247) form to a slight extent in the first reaction. They can be removed by shaking the distillate with aqueous hydrochloric acid (whereby the isonitrile is converted into formic acid and a primary amine), until the unpleasant odour of the isocyanides has disappeared, then neutralizing with *soda* and drying the nitriles with calcium chloride.

(2) By heating alkyl isocyanides or alkyl carbylamines (p. 247):

$$CH_3CH_2NC \xrightarrow{250^\circ} CH_3CH_2CN.$$

(3) By the dry distillation of ammonium salts of the acids with P_2O_5, or some other dehydrating agent (hence the term *acid nitrile*).

$$\underset{\text{Ammonium Acetate.}}{CH_3.CO.O.NH_4} - 2H_2O = \underset{\text{Acetonitrile.}}{CH_3.CN.}$$

The corresponding acid amide is an intermediate product.

(4) By the removal of water from the amides of the acids when these are heated with P_2O_5, P_2S_5, or phosphorous pentachloride (see amide chlorides, p. 277):

$$CH_3.CO.NH_2 + PCl_5 = CH_3.CN + POCl_3 + 2HCl$$
$$5CH_3.CO.NH_2 + P_2S_5 = 5CH_3.CN + P_2O_5 + 5H_2S.$$

(5) By the distillation of fatty acids with potassium thiocyanate (B. **5**, 669), or lead thiocyanate (B. **25**, 419), during which a complicated reaction occurs. It is assumed that a thioamide is first formed which loses H_2S, changing into the nitrile, or that a carboxyl is exchanged for a CN-group.

(6) Primary amines, containing more than five carbon atoms, are converted, by potassium hydroxide and bromine, into nitriles:

$$C_7H_{15}CH_2NH_2 + 2Br_2 + 2KOH = C_7H_{15}CH_2NBr_2 + 2KBr + 2H_2O$$
$$C_7H_{15}CH_2NBr_2 + 2KOH = C_7H_{15}CN + 2KBr + 2H_2O.$$

As the primary amines can be obtained from acid amides containing a carbon atom more, these reactions will serve for the breaking-down of the fatty acids (p. 263).

(7) Nitriles result when aldoximes are heated with acetic anhydride or with thionyl chloride (B. **28**, R. 227):

$$CH_3CH{=}N.OH + (CH_3CO)_2O = CH_3C{\equiv}N + 2CH_3.COOH.$$

(8) On the application of heat to cyanacetic acid and alkylized cyanacetic acid, nitriles result:

$$CNCH_2.CO_2H = CNCH_3 + CO_2.$$

The nitriles occur already formed in bone-oils and in gas tar.

Historical.—Pelouze (1834) discovered propionitrile on distilling barium ethyl sulphate with potassium cyanide (A. **10**, 249). *Dumas* (1847) obtained acetonitrile by distilling ammonium acetate alone, or with P_2O_5; the same occurred with the latter reagent and acetamide (p. 277). *Dumas*, *Malaguti* and *Leblanc* (A. **64**, 334) on the one hand, and *Frankland* and *Kolbe* (A. **65**, 269, 288, 299) on the other, demonstrated (1847) the conversion of the nitriles into their corresponding acids by means of potassium hydroxide or dilute acids, and thus showed what importance the acid nitriles possessed for synthetic organic chemistry.

Properties and Reactions.—The nitriles are liquids, usually insoluble in water, possessing an ethereal odour, and distilling without decomposition.

Their reactions are based upon the easy disturbance of the triple union between nitrogen and carbon, and are mostly additive reactions. *Acid nitriles may be considered to be unsaturated compounds*, in the same sense as are the aldehydes and ketones (pp. 23, 190). Their neutral character distinguishes them from hydrocyanic acid, the nitrile of formic acid, which they resemble as regards the reactions of their C≡N-group.

(1) Nascent hydrogen converts them into primary amines (p. 158) (*Mendius*). This reduction is most easily accomplished by means of metallic sodium and absolute alcohol (B. 22, 812).

(2) The nitriles unite with the halogen acids, forming amide and imide halides (p. 281).

(3) Under the influence of concentrated sulphuric acid they take up water and become converted into acid amides (p. 274). When heated to 100° with water the acid amides first formed absorb a second molecule of water and change to the fatty acid and ammonia. The nitriles are more readily hydrolyzed by heating them with alkalis or dilute acids (hydrochloric or sulphuric acid). Esters are produced when the acids, in a solution of absolute alcohol, act on the nitriles.

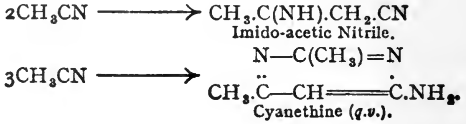
(4) The nitriles form thiamides with H_2S (p. 281).

(5) They combine with alcohols and HCl to form imido-ethers (p. 281).

(6) With fatty acids and fatty acid anhydrides they yield secondary and tertiary amides (p. 276).

(7) The nitriles become converted into amidines with ammonia and the amines (p. 282).

(8) Hydroxylamine unites with them to form amidoximes (p. 283). Metallic sodium induces in them peculiar polymerizations. In ethereal solution, dimolecular nitriles result: *imides* of *β-ketonic nitriles*. All these reactions depend upon the additive power of the nitriles, the triple carbon-nitrogen union being broken. If, however, sodium acts on the pure nitriles at a temperature of 150° the products are *trimolecular nitriles*, so-called *cyanethines* (*q.v.*), *pyrimidine* derivatives:



Imido-acetic Nitrile.

Cyanethine (*q.v.*).

Acetonitrile, *Methyl Cyanide* [Ethane Nitrile], CH_3CN, m.p. −41° C., b.p. 81·6°, D_{15}=0·789, is a liquid with an agreeable odour. It is usually prepared by distilling acetamide with P_2O_5. Consult the general description of acid nitriles for its methods of formation, its history and its reactions. It may, however, be mentioned here that acetonitrile can be produced from hydrocyanic acid and diazomethane (B. 28, 857). It combines with Cu_2Cl_2 to form $(CH_3CN)_2Cu_2Cl_2$ (C. 1898, II. 859).

Higher Homologous Nitriles.—*Propionitrile, Ethyl Cyanide,* [Propane Nitrile], $C_2H_5.CN$, b.p. 98°, D_0 0·801.

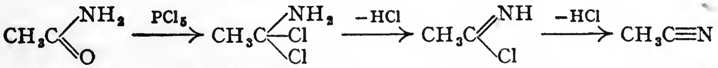
n-*Butyronitrile*, b.p. 118·5°, has the odour of bitter-almond oil. *Isobutyronitrile*, b.p. 107°; n-*Valeronitrile*, b.p. 140·4°; *Isopropyl Acetonitrile*, b.p. 129°; *Methyl Ethylacetonitrile*, b.p. 125°; *Trimethyl Acetonitrile*, m.p. 15–16°, b.p. 105–106°; *Isobutyl Acetonitrile*, b.p. 154°; *Diethyl Acetonitrile*, b.p. 144–146°; *Dimethyl Ethyl Acetonitrile*, b.p. 128–130°; n-*Œnanthyl Nitrile* b.p. 175–178°;

n-*Caprilonitrile*, b.p. 198-200°; *Pelargonitrile*, b.p. 214–216°; *Methyl* n-*Hexyl-Acetonitrile*, b.p. 206°; *Lauronitrile*, b.p.$_{100}$ 198°; *Tridecylonitrile*, b.p. 275°; *Myristonitrile*, m.p. 19°, b.p. 226·5°; *Palmitonitrile*, m.p. 29°, b.p.$_{100}$ 251·5°; *Cetyl Cyanide*, m.p. 53°; *Stearonitrile*, m.p. 41°, b.p.$_{100}$ 274·5°.

Several classes of compounds bear genetic relations to the acid amides and nitriles, but these will be considered after the nitriles.

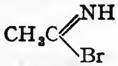
10. AMIDE CHLORIDES AND 11. IMIDE CHLORIDES (*Wallach*, A. **184**, 1)

The amide chlorides are the first unstable products formed during the action of PCl_5 on acid amides. They lose hydrochloric acid and become converted into *imide chlorides*, which by a further separation of hydrochloric acid yield nitriles:

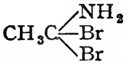


Acetamide. (Acetamide Chloride.) (Acetimide Chloride.) Acetonitrile.

The addition of HCl to the nitriles produces the imide chlorides. Hydrobromic and hydriodic acids are added more readily than hydrochloric acid to nitriles (B. **25**, 2541):



Acetimide Bromide.



Acetamide Bromide.

Acetamide Iodide.

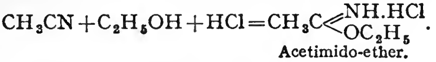
If a hydrogen atom of the amide group be replaced by an alcohol radical, the imide chlorides will be more stable. On being heated, however, they lose hydrochloric acid in part and pass into chlorinated bases.

(1) Water changes the imide chlorides back into *acid amides*. The chlorine atom of these bodies is as reactive as the chlorine atom of the acid chlorides. (2) Ammonia and the primary and secondary amines change the imide chlorides to *amidines* (p. 282). (3) Hydrogen sulphide converts the imide chlorides into thiamides.

12. IMIDO-ETHERS* (*Pinner*, B. **16**, 353, 1654; **17**, 184, 2002)

The imido-ethers may be regarded as the esters of the imido-acids, $R'.C{<}{\scriptstyle\begin{matrix}NH\\OH\end{matrix}}$, a formula which has, in recent times, been proposed for the acid amides (p. 275); (comp. also the Thiamides).

The *hydrochlorides* of the *Imido-ethers* are produced by the action of HCl on an ethereal mixture of a nitrile with an alcohol (in molecular quantities):



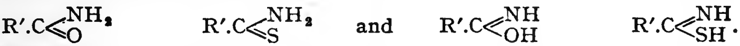
$$CH_3CN + C_2H_5OH + HCl = CH_3C{<}\begin{matrix}NH.HCl\\OC_2H_5\end{matrix}.$$

Acetimido-ether.

Formimido-ether (p. 243). **Acetimido-Ethyl Ether,** b.p. 94°, when liberated from its HCl-salt by means of NaOH, is a peculiar-smelling liquid. Ammonia and the amines convert the imido-ethers into *amidines*. Shaking the imido-ether hydrochlorides with alcohol produces *ortho-esters* (p. 284).

13. THIAMIDES

As in the case of the acid amides (p. 274), so here with the thiamides two formulas are possible:



$$R'.C{<}\begin{matrix}NH_2\\O\end{matrix} \qquad R'.C{<}\begin{matrix}NH_2\\S\end{matrix} \quad \text{and} \quad R'.C{<}\begin{matrix}NH\\OH\end{matrix} \qquad R'.C{<}\begin{matrix}NH\\SH\end{matrix}.$$

---

* Die Imidoaether und ihre Derivate von A. Pinner, 1892.

The thiamides are formed (1) by the action of phosphorus sulphide on the acid amides; (2) by the addition of H_2S to the *nitriles* (p. 280):

$$\underset{\text{Acetonitrile.}}{CH_3.CN}+H_2S=\underset{\text{Thiacetamide.}}{CH_3.CS.NH_2}.$$

(1) The thiamides are readily broken up into fatty acids, H_2S, NH_3 and amines.

(2) They yield *thiazole* derivatives with chloracetic ester, chloracetone, and similar bodies.

(3) Ammonia converts them into amidines.

(4) The action of hydroxylamine results in the production of oxamidines.

Thiacetamide, m.p. 108° (A. **192**, 46; B. **11**, 340). *Thiopropionamide,* m.p. 42–43° (A. **259**, 229).

14. THIO-IMIDO-ETHERS

are derived from the imidothiohydrin form of the thioamides. They are prepared, analogously to the imido-ethers, from the nitriles with mercaptans and HCl (B. **36**, 3464). *Acetimido-Thiophenyl Ether,* $CH_3C\begin{smallmatrix}\nearrow NH\\ \searrow SC_6H_5\end{smallmatrix}$, is obtained from its hydrochloride by the action of sodium hydroxide. It is an unstable yellow syrup. The *hydrochloride,* m.p. 120°, with decomposition, is prepared from acetonitrile, thiophenol (Vol. II.) and HCl.

15. AMIDINES, $R.C\begin{smallmatrix}\nearrow NH\\ \searrow NH_2\end{smallmatrix}$ (A. **184**, 121; **192**, 46)

The amidines, containing an amide and imide group, whose hydrogen atoms are replaceable by alkyls, may be considered to be derivatives of the acid amides, in which the carbonyl oxygen is replaced by the imide group:

$$\underset{\text{Acetamide.}}{CH_3CONH_2} \qquad \underset{\text{Acetamidine.}}{CH_3C(NH)NH_2}.$$

They are produced:

(1) From the imide chlorides and thiamides, by the action of ammonia or amines.

(2) From the nitriles by heating them with ammonium chloride.

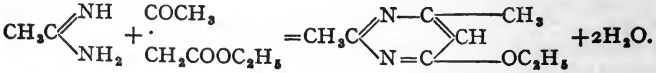
(3) From the amides of the acids when treated with HCl (B. **15**, 208):

$$2CH_3CONH_2=CH_3C\begin{smallmatrix}\nearrow NH\\ \searrow NH_2\end{smallmatrix}+CH_3CO_2H.$$

(4) From the imido-ethers (p. 281) when acted on with ammonia and amines (B. **16**, 1647; **17**, 179).

The amidines are mono-acid bases. In a free condition they are very unstable. The action of various reagents on them induces absorption of water, the imide group splits off, and acids or amides of the acids are regenerated.

β-Ketonic esters convert them into *pyrimidines, e.g.* acetamidine hydrochloride and acetoacetic ester yield *dimethyl ethoxypyrimidine,* m.p. 192° (comp. polym. acetonitrile, p. 280):



Formamidine (p. 244).

Acetamidine, *Acediamine, Ethenyl Amidine,* $CH_3C(NH_2)NH$; *hydrochloride,* m.p. 163°. The acetamidine, separated by alkalis, reacts strongly alkaline and readily breaks up into NH_3 and acetic acid.

16. HYDROXAMIC ACIDS, $R.C\begin{smallmatrix}\nearrow N.OH\\ \searrow OH\end{smallmatrix}$

These are produced by the action of hydroxylamine on acids, amides, esters, and chlorides. They are characterized by containing an oximido- or isonitroso-group in place of a carboxylic oxygen atom (B. **22**, 2854). Another method of preparation is from aldehydes and nitrohydroxylaminic acids, O:N(OH):N(OH) (C. 1901, II. 770).

$$CH_3COH+N_2O_3H_2=CH_3C(NOH)OH+HNO_2.$$

Benzene sulphohydroxamic acid, $C_6H_5SO_2NHOH$, behaves similarly, by forming acyl hydroxamic acids and benzene sulphinic acid, $C_6H_5SO_2H$, with aldehydes (C. 1901, II. 99).

They are crystalline compounds, acid in character, and form an insoluble copper salt in ammoniacal copper solutions. Ferric chloride imparts a cherry-red colour to both their acid and neutral solutions.

Acetohydroxamic Acid, $CH_3C(NOH)OH+\frac{1}{2}H_2O$, m.p. 59°. It dissolves very easily in water and alcohol, but not in ether.

Formhydroxamic Acid (see p. 224).

17. HYDROXIMIC ACID CHLORIDES, $RC{<}^{NOH}_{Cl}$

When chlorine is passed into a solution of acetaldoxime, a precipitate of colourless crystals of *Nitrosochlorethane,* $CH_3CH{<}^{Cl}_{NO}$, m.p. 65°, is formed. They melt to form a blue liquid and dissolve in ether forming a blue solution. From both the colour gradually disappears on standing owing to a change into *Acetohydroximic Acid Chloride,* $CH_3C{<}^{NOH}_{Cl}$, m.p. -3°, a colourless, easily decomposed liquid. Silver nitrate converts it into acetonitrolic acid (see below); chlorine produces *Nitrosodichlorethane,* $CH_3CCl_2.NO$, b.p. 68°, a deep blue oil (B. **35,** 3101). Acetohydroximic acid chloride is also obtained directly by the action of chlorine on a hydrochloric acid solution of acetaldoxime (B. **40,** 1677).

18. NITROLIC ACIDS, $R.C{<}^{N.OH}_{NO_2}$ (p. 153)

As these bodies are genetically related to the mononitroparaffins, they have already been discussed immediately after them.

19. AMIDOXIMES or OXAMIDINES, $R.C{<}^{N.OH}_{NH_2}$

These compounds may be regarded as amidines, in which a H atom of the amide or imide group has been replaced by hydroxyl. They are formed: by the action of hydroxylamine on the amidines (p. 282); by the addition of hydroxylamine to the nitriles (B. **17,** 2746):

$$\underset{\text{Acetonitrile.}}{CH_3CN}+NH_2OH=\underset{\text{Ethenyl Amidoxime.}}{CH_3C{<}^{NH_2}_{NOH}},$$

and by the action of hydroxylamine on thiamides (B. **19,** 1668):

$$CH_3CSNH_2+NH_2OH=CH_3.C{<}^{NH_2}_{NOH}+H_2S.$$

The amidoximes are crystalline, very unstable compounds, which readily break down into hydroxylamine, and the acid amides or acids.

Methenyl Amidoxime, *Formamidoxime* or *Isouretine* (p. 244).

Ethenyl Amidoxime, $CH_3C{<}^{NOH}_{NH_2}$, m.p. 135°. *Hexenyl Amidoxime,* m.p. 48°. *Heptenyl Amidoxime,* m.p. 48–49° (B. **25,** R. 637). *Lauryl Amidoxime,* m.p. 92–92·5°. *Myristyl Amidoxime,* m.p. 97°. *Palmityl Amidoxime,* m.p. 101·5–102°. *Stearyl Amidoxime,* m.p. 106–106·5° (B. **26,** 2844).

20, 21. HYDROXAMIC OXIME (*Hydroxyamido-oximes*), NITROSOXIMES (*Nitrosolic Acids*)

and allied bodies are obtained from the hydroximic acid chlorides and nitrolic acids (A. **353**, 65; B. **40**, 1676).

Acetohydroxamic Oxime, *Acetohydroxyamido-oxime,* $CH_3C{<}\begin{smallmatrix}NHOH\\NOH\end{smallmatrix}$, results from the interaction of acetohydroximic acid chloride and hydroxylamine, or from the reduction of ethyl nitrolic acid (p. 153) with sodium amalgam. It is unstable in the free state, but is known as a colourless *hydrochloride,* m.p. 156°, with decomposition, and as a red brown *copper salt,* $C_2H_4O_2N_2Cu+2H_2O$. Dilute alkali changes it into an unstable strongly coloured *azo-body,* $CH_3C(:NOH).N{=}N.C(:NOH)CH_3$, which partially changes into its more stable and equally coloured isomer, *azaurolic acid,* $CH_3C(:NOH).NHN:C(NO)CH_3$, and partially breaks down into ethyl nitrosolic acid and acetamide oxime:

$$CH_3C(NOH).N{=}N.C(:NOH)CH_3 \xrightarrow{H_2O} CH_3C(:NOH)NO+H_2NC(NOH)CH_3.$$

Acetonitroso-oxime, *Ethyl Nitrosolic Acid,* $CH_3C{<}\begin{smallmatrix}NO\\NOH\end{smallmatrix}$, is prepared from acetohydroxamic oxime by oxidation with bromine. It is characterized by its deep blue *potassium salt,* $C_2H_3N_2O_2K$. It is readily decomposed by acids.

For further reactions, see above.

22, 23. HYDRAZIDINE and HYDRAZO-OXIME,

such as $RC{<}\begin{smallmatrix}N.NHC_6H_5\\NH_2\end{smallmatrix}$ and $RC{<}\begin{smallmatrix}NH.NHC_6H_5\\NOH\end{smallmatrix}$, see Vol. II., and B. **35**, 3271.

24. ORTHO-FATTY ACID DERIVATIVES

The ortho-esters of the fatty acids are obtained similarly to orthoformic ester (p. 244) (1) from the imido-ether hydrochlorides (p. 281) and alcohols (B. **40**, 3020); from the orthotrichlorides and sodium alcoholate; (3) synthetically from the orthocarbonic acid esters and alkyl magnesium halides (B. **38**, 561).

Orthoacetic Triethyl Ester, $CH_3C(OC_2H_5)_3$, b.p.$_{748}$ 145°, b.p.$_{13}$ 42°, is a colourless pleasant-smelling liquid, but differing in odour from the ordinary ester.

Orthopropionic Ester, $CH_3CH_2C(OC_2H_5)_3$, b.p.$_{66}$ 161°, b.p.$_{12}$ 54°. *Ortho-Acetyl Trichloride, Methyl Chloroform, Ethenyl Trichloride.* 1,1,1-*Trichlorethane,* CH_3CCl_3, b.p. 74·5°, is formed together with 1, 1, 2, Trichlorethane, by the action of chlorine on ethylidine chloride (A. **195**, 183).

Methyl Nitroform, 1,1,1-*Trinitroethane* is discussed with the nitroparaffins (p. 156).

Orthoacetic Tripiperide, $CH_3.C(NC_5H_{10})_3$, b.p. 261°, is obtained by heating together methyl chloroform and piperidine. It forms a strongly alkaline, colourless liquid, of a peculiar odour: *hydrochloride,* $CH_3.C(N.C_5H_{10}.HCl)_3$, does not melt at 260°.

HALOGEN SUBSTITUTION PRODUCTS OF THE FATTY ACIDS

The reactions leading to the substituted fatty acids are partly the same as those employed in the formation of the halogen substitution products of the paraffins.

(1) *Direct substitution of the hydrogen* of the hydrocarbon residue, joined to carboxyl, by halogens.

(*a*) Chlorine in sunlight, or with the addition of water and iodine, or sulphur (B. **25**, R. 797), or phosphorus (B. **24**, 2209); or by the action of sulphuryl chloride on the fatty acids (C. 1905, I. 414).

(*b*) Bromine in sunlight, or with the addition of water in a closed tube at a more elevated temperature, or with the addition of sulphur (B. **25**, 3311), or phosphorus (B. **24**, 2209).

(*c*) Iodine with iodic acid, or bromo-fatty acids with potassium iodide.

The *acid chlorides, bromides,* or *acid anhydrides* are more readily substituted than the free acids. This reaction can be brought about most suitably by the addition of the required quantity of chlorine dissolved in CCl_4 to a solution of the chloride in the same solvent. Each liquid is cooled externally, and the mixture is made in full sunlight (B. **34**, 4047). When chlorine or bromine, in the presence of phosphorus, acts on the fatty acids (method of *Hell-Volhard*), acid chlorides and bromides result; these are then subjected to substitution. The final products are halogen-acid chlorides or halogen-acid bromides:

$$3CH_3.CO_2H+P+11Br=3CH_2Br.COBr+HPO_3+5HBr.$$

However, substitution only takes place in a mono-alkyl or dialkyl-acetic acid at the *a*-carbon atom. Hence, *trimethylacetic acid* cannot be chlorinated or brominated. Consequently the behaviour of a fatty acid towards chlorine or bromine and phosphorus indicates whether or not a trialkyl-acetic acid is present (B. **24**, 2209).

(2) *Addition of Halogen Acids to Unsaturated Monocarboxylic Acids.*—The halogen enters at a point as far as possible from the carboxyl group, *e.g.*:

$$\underset{\text{Acrylic Acid.}}{CH_2{:}CH.CO_2H}\left\{\begin{array}{l}\xrightarrow{HCl} CH_2Cl.CH_2.CO_2H\\ \xrightarrow{HBr} CH_2Br.CH_2.CO_2H\\ \xrightarrow{HI} CH_2I.CH_2.CO_2H\end{array}\right.\quad\left.\begin{array}{l}\beta\text{-Chloro-}\\ \beta\text{-Bromo-}\\ \beta\text{-Iodo-}\end{array}\right\}\text{propionic acid.}$$

(3) *Addition of Halogens to Unsaturated Monocarboxylic Acids.*—Whenever possible the chlorine is allowed to act in a CCl_4 solution. Bromine often reacts without the help of a solvent, also in the presence of water, CS_2, glacial acetic acid and chloroform.

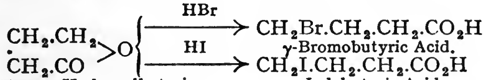
(4) Action of the *halogen acids* (*a*) on hydroxymonocarboxylic acids:

$$\text{Hydracrylic Acid}\quad CH_2(OH)CH_2CO_2H \xrightarrow[120^\circ]{HCl} CH_2Cl.CH_2.CO_2H\quad \beta\text{-Chloropropionic Acid.}$$

$$\text{Lactic Acid:}\quad CH_3CH(OH)CO_2H \xrightarrow{HBr} CH_3CHBrCO_2H\quad a\text{-Bromopropionic Acid.}$$

$$\text{Glyceric Acid:}\quad CH_2(OH)CH(OH)CO_2H \xrightarrow{HI} CH_2I.CH_2.CO_2H\quad \beta\text{-Iodopropionic Acid.}$$

(4*b*) On lactones, cyclic anhydrides of γ- or δ-hydroxy acids:



$$\begin{matrix}CH_2.CH_2\\ \vert\\ CH_2.CO\end{matrix}\!>\!O\left\{\begin{array}{l}\xrightarrow{HBr} \underset{\gamma\text{-Bromobutyric Acid.}}{CH_2Br.CH_2.CH_2.CO_2H}\\ \xrightarrow{HI} \underset{\gamma\text{-Iodobutyric Acid.}}{CH_2I.CH_2.CH_2.CO_2H}\end{array}\right.$$

Butyrolactone γ-Hydroxylbutyric Acid Lactone.

(5) Action of the *phosphorus halides*, particularly PCl_5, on hydroxymonocarboxylic acids or their nitriles (C. 1898, I. 22). The product is the chloride of a chlorinated acid, which water transforms into the acid:

$$\underset{\text{Lactic Acid.}}{CH_3.CHOH.COOH}+2PCl_5=\underset{a\text{-Chloropropionyl Chloride.}}{CH_3.CHCl.COCl}+2POCl_3+2HCl.$$

Furthermore, halogen fatty acids are obtained like the parent acids (6) by the oxidation of *chlorinated alcohols* or *aldehydes* (p. 203) with nitric acid, chromic acid, potassium permanganate or potassium chlorate (B. **18**, 3336):

$$a\beta\text{-Dichlorhydrin:}\quad CH_2Cl.CHCl.CH_2OH \xrightarrow{2O} CH_2Cl.CHCl.CO_2H\quad a\beta\text{-Dichloropropionic Acid.}$$

$$\text{Chloral:}\quad CCl_3CHO \xrightarrow{\quad O\quad} CCl_3COOH\quad \text{Trichloracetic Acid.}$$

(7) By the action of halogen acids on *diazo-fatty acid esters* (see Glyoxylic Acid):

$$CHN_2.CO_2C_2H_5+HCl=CH_2Cl.CO_2C_2H_5+N_2.$$

(8) When the halogens act on *diazo-fatty acid esters:*

$$CHN_2CO_2C_2H_5+I_2=CHI_2CO_2C_2H_5+N_2.$$

Isomerism and Nomenclature.—Structurally, isomeric halogen substitution products of the fatty acids are first possible with propionic acid. To indicate the position of the halogen atoms, the carbon atom to which the carboxyl group is attached is marked α, whilst the other carbon atoms are successively called β, γ, δ, ϵ, etc. The two monochloropropionic acids are distinguished as α- and β-chloropropionic acids, whilst the three isomeric dichloropropionic acids are the $\alpha\alpha$-, $\beta\beta$- and $\alpha\beta$-dichloropropionic acids, etc.

Behaviour.—The introduction of substituting halogen atoms increases the acid character of the fatty acids. The halogen fatty acids, like the parent acids, yield, by analogous treatment, *esters, chlorides, anhydrides, amides, nitriles*, etc.

On the velocity of ester formation and the electric conductivity of the α-, β-, γ-, and δ-halogen fatty acids, see A. **319,** 369.

Reactions.—(1) Nascent hydrogen causes the halogen substitution products of the fatty acids to revert to the parent acids—*retrogressive substitution.*

The reactions of the monohalogen fatty acids, which bear the same relation to the *alcohol acids* or *hydroxy-acids* as the alkylogens do to the alcohols, are especially important. In both classes the halogen atoms enter the reaction under similar conditions.

(2) Boiling water, alkali hydroxides, or an alkali carbonate solution generally brings about an exchange of hydroxyl for the halogen atom (A. **342,** 115).

However, in monohalogen products, the position of the halogen atom, with reference to carboxyl, will materially affect the course of the reaction: α-halogen acids yield α-hydroxy acids, β-halogen acids split off the halogen acid and become converted into unsaturated acids with the formation also of β-hydroxy acids (A. **342,** 127); γ-halogen acids, on the contrary, yield γ-hydroxy acids, which readily yield *lactones* (B. **219,** 322):

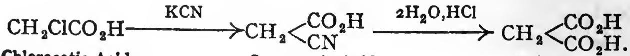
$$CH_2ClCOOH \xrightarrow{H_2O} CH_2(OH)CO_2H$$

$$CH_2ClCH_2COOH \xrightarrow{H_2O} CH_2{=}CHCO_2H$$

$$CH_2ClCH_2CH_2COOH \xrightarrow{H_2O} CH_2\overline{OCH_2CH_2C}O.$$

(3) Ammonia converts the halogen fatty acids into amido-acids.

Nucleus-synthetic Reactions.—(4) Potassium cyanide produces cyano-fatty acids—*the mononitrile of dibasic acids*, which hydrochloric acid changes to dibasic acids. They will be considered after the latter:

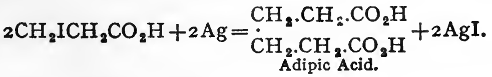


$$CH_2ClCO_2H \xrightarrow{KCN} CH_2{<}\begin{matrix}CO_2H\\CN\end{matrix} \xrightarrow{2H_2O,HCl} CH_2{<}\begin{matrix}CO_2H\\CO_2H.\end{matrix}$$

Chloracetic Acid. Cyanacetic Acid. Malonic Acid.

The monohalogen acids furnish a means of building up the dicarboxylic acids from the monocarboxylic acids.

(5) *Dicarboxylic acids* have been obtainde from mono-halogen carboxylic acids by means of metals:



$$2CH_2ICH_2CO_2H+2Ag=\begin{matrix}CH_2.CH_2.CO_2H\\ \vdots\\ CH_2.CH_2.CO_2H\end{matrix}+2AgI.$$

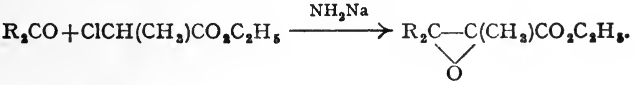
Adipic Acid.

(6) and (7) The esters of the mono-halogen fatt yacids have been applied in connection with the acetoacetic ester and malonic ester syntheses, and as results we have β-ketone dicarboxylic acids, β-ketone-tricarboxylic acids, and tri- and tetracarboxylic acids.

(8) The esters of the halogen fatty acids can be changed into halogen zinc or halogen magnesium fatty acid esters by means of the free metal; in the presence of aldehydes and ketones, salts of the higher *hydroxy-fatty acid esters* are formed:

$$RCHO+BrCH(CH_3)CO_2C_2H_5 \xrightarrow{Zn} RCH(OZnBr).CH(CH_3)CO_2C_2H_5.$$

(9) The final product of condensation of α-halogen fatty acid esters and ketones by means of sodium amide are the *ethylene oxide carboxylic esters* (*glycidic acid esters*):



Substitution Products of Acetic Acid.

Chlorine Substitution Products.—The relations of the three chloracetic acids to the oxygen derivatives, whose chlorides they may be considered to be, are evident in the following tabulation (comp. pp. 117, 206):

Monochloracetic Acid,	CH_2ClCO_2H,	corresponds with	*Glycollic Acid,*	$CH_2OH.CO_2H$
Dichloracetic Acid,	$CHCl_2CO_2H$,	,, ,,	*Glyoxylic Acid,*	$CHO.CO_2H$
Trichloracetic Acid,	CCl_3CO_2H,	,, ,,	*Oxalic Acid,*	$CO_2H.CO_2H$

Monochloracetic Acid, $CH_2Cl.CO_2H$, m.p. 62°, b.p. 185–187°, solidifies after fusion to an *unstable modification,* m.p. 52°. This slowly reverts spontaneously to the ordinary acid (B. **26**, R. 381). On the preparation of the acids from acetic acid and sulphuryl chloride, see C. 1905, I. 414. Its sodium and silver salts, on the application of heat, yield *polyglycollide.*

When monochloracetic acid is heated with alkalis or water, the chlorine is replaced by the hydroxyl group, and we get *Hydroxy Acetic Acid* or *Glycollic Acid* (*q.v.*). *Amino-acetic Acid,* or *Glycocoll,* results when the monochlor-acid is digested with ammonia.

The *ethyl ester,* b.p. 143·5°; *chloride,* b.p. 106°; *bromide,* b.p. 127°; *anhydride,* m.p. 46°, b.p.$_{11}$ 110° (B. **27**, 2949); *amide,* m.p. 116°, b.p. 224–225°; *nitrile,* b.p. 124°.

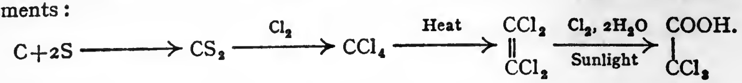
Dichloracetic Acid, $CHCl_2CO_2H$, b.p. 190–191°, is produced when chloral is heated with potassium cyanide or ferrocyanide and some water. If alcohol replace the water, dichloracetic esters are formed (B. **10**, 2124):

$$CCl_3CHO+H_2O+KCN=CHCl_2CO_2H+KCl+HCN.$$

When its silver salt is boiled with a little water, *glyoxylic acid* (*q.v.*) is produced. *Methyl ester,* b.p. 142–144°; *ethyl ester,* b.p. 158°; *anhydride,* b.p. 214–216°, with decomposition; *chloride,* b.p. 107–108°; *amide,* m.p. 98°, b.p. 234°; *nitrile,* b.p. 113°.

Trichloracetic Acid, CCl_3CO_2H, m.p. 55°, b.p. 195°, the officinal *Acidum trichloraceticum,* was first prepared by *Dumas* (1839) when he allowed chlorine to act in the sunlight on acetic acid (A. **32**, 101). Without essentially changing the chemical character, three hydrogen atoms of the acetic acid were replaced by chlorine—a fact upon which *Dumas* then erected the *type theory* (p. 18). *Kolbe* (1845) made the acid by the oxidation of chloral with concentrated nitric acid

(A. **54**, 183), and demonstrated how it could be prepared synthetically from its elements:



$$C+2S \longrightarrow CS_2 \xrightarrow{Cl_2} CCl_4 \xrightarrow{Heat} \begin{matrix} CCl_2 \\ \| \\ CCl_2 \end{matrix} \xrightarrow[Sunlight]{Cl_2,\ 2H_2O} \begin{matrix} COOH. \\ | \\ CCl_3 \end{matrix}$$

The carbon disulphide resulting from carbon and sulphur is converted by the chlorine into carbon tetrachloride, which on the application of heat becomes converted into perchlorethylene, $CCl_2=CCl_2$ (p. 97), and it, in turn, by the action of chlorine and water, aided by sunlight, yields trichloracetic acid. This was the first synthesis of acetic acid, for *Melsens* had previously shown that potassium amalgam in aqueous solution reduced trichloracetic acid to acetic acid (p. 256).

Boiling with water decomposes trichloracetic acid into chloroform (p. 245) and CO_2, whilst excess of alkali produces formic acid and a carbonate (A. **342**, 122). Electrolysis gives rise to the formation of perchloracetic trichloromethyl ester (C. 1897, II. 475).

The *methyl ester*, b.p. 152·5°; *ethyl ester*, b.p. 164°, are obtained from the acid and alcohols (B. **29**, 2210; C. 1901, II. 1333). *Trichloracetyl Chloride, Perchloracetaldehyde*, b.p. 118°, is formed when ozonized air or SO_3 (A. **308**, 324) acts on perchlorethylene (B. **27**, R. 509) (comp. synthesis of trichloracetic acid from CS_2); *bromide*, b.p. 143°; *anhydride*, b.p. 224°; *amide*, m.p. 141°, b.p. 239°; *nitrile*, b.p. 83°. *Perchloracetic Trichloromethyl Ester*, $CCl_3.CO_2CCl_3$, m.p. 34°, b.p. 192° (A. **273**, 61).

Bromacetic Acids.—*Monobromacetic Acid*, $CH_2Br.CO_2H$, m.p. 50–51°, b.p. 208°; *ethyl ester*, b.p. 159°; *chloride*, b.p. 134°; *bromide*, $CH_2Br.COBr$, b.p. 150° (pp. 98, 270); *anhydride*, b.p. 245°; *amide*, m.p. 91°; *nitrile*, b.p. 148–150° (B. **38**, 2694).

Dibromacetic Acid, $C_2H_2Br_2O_2$, m.p. 54–56°, b.p. 232–235°; *ethyl ester*, b.p. 192°; *bromide*, $CHBr_2.COBr$ (pp. 98, 270), b.p. 194°; *amide*, m.p. 156° (B. **38**, 2695).

Tribromacetic Acid, CBr_3CO_2H, m.p. 135°, b.p. 246° with decomposition, results from the interaction of perbromethylene and nitric acid (A. **308**, 324). Boiling water or alkali decomposes it similarly to trichloracetic acid (see above). *Ethyl ester*, b.p. 225°; *bromide*, b.p. 220–225°; *amide*, m.p. 120–121°; *nitrile*, b.p. 170°, is a dark red liquid, which HCl changes to the polymeric *trinitrile*, m.p. 129° (B. **27**, R. 730).

Iodoacetic Acids.—*Moniodoacetic Acid*, CH_2ICO_2H, m.p. 82° (C. 1901, I. 665).

Di-iodoacetic Acid, $CHI_2.CO_2H$, m.p. 110°.

Tri-iodoacetic Acid, m.p. 150°. The last two compounds have been obtained from malonic acid and iodic acid (B. **26**, R. 597). (Comp. iodoform, p. 246.)

Fluoracetic Acids.—*Monofluoracetic Acid*, $CH_2F.COOH$, m.p. 33°, b.p. 165°, is obtained by the hydrolysis of its *methyl ester*, b.p. 104°, which in turn is prepared from methyl iodo-acetate and mercury or silver fluoride. *Difluoracetic acid*, CHF_2COOH, b.p. 134°, is prepared by oxidation of difluorethyl alcohol (from difluor-ethyl bromide). In these compounds the fluorine atom is held relatively firmly in the molecule (J. 1896, 759; C. 1903, II. 709). *Dibromofluoracetic acid*, $CBr_2F.COOH$, m.p. 26°, b.p. 198°; *ethyl ester*, b.p. 173°, possesses a camphor-like odour; *fluoride*, $CBr_2F.COF$, b.p. 75°, is formed from symmetrical (?) dibromodifluorethylene by the absorption of oxygen (C. 1898, II. 702).

Substitution Products of Propionic Acid.

The α-monohaloid propionic acids contain an asymmetric carbon atom; hence their esters, for example, are known in an active form. They are prepared according to the methods 4*a* and 5 (p. 285). The β-monohalogen acids are derived from acrylic acid by method 3 (p. 285), and β-iodopropionic acid from glyceric acid by method 4*a*.

α-Chloropropionic Acid, $CH_3CHClCO_2H$, b.p. 186°; *ethyl ester*, b.p. 146 ; *chloride*, 109–110°; *amide*, 80°; *nitrile*, b.p. 121–122°, is prepared from acetaldehyde cyanohydrin and PCl_5 (B. **34**, 4049). **α-Bromopropionic Acid**, m.p. 24·5°, b.p. 205°, is resolved into its optically active components by cinchonine; *ethyl ester*, b.p. 162°; *bromide*, b.p. 153° (A. **280**, 247); *anhydride*, b.p.$_5$ 120° (B. **27**, 2949). Dextro-rotatory *α-Chloro-* and *α-Bromopropionic esters* are obtained from sarcolactic acid (B. **28**, 1293). *α-Iodopropionic Acid*, m.p. 45°, is prepared from propionyl chloride and iodine chloride (B. **36**, 4392).

β-Chloropropionic Acid, $CH_2ClCH_2CO_2H$, m.p. 41·5°. b.p. 203–204°; *methyl* *ester*, b.p. 156°; *ethyl ester*, b.p. 162°; *chloride*, b.p. 143–135°. **β-Bromopropionic Acid**, m.p. 61·5°; *ethyl ester*, b.p.$_{10}$ 69–70°; *bromide*, b.p. 154–155°. **β-Iodopropionic Acid**, m.p. 82°; *methyl ester*, b.p. 188°; *ethyl ester*, 202°; *amide*, m.p. 100° (B. **21**, 24, 97), is formed by boiling the ester with sodium amalgam and subsequently hydrolyzing the *mercury dipropionic acid*, $Hg(CH_2CH_2COOH)_2$ formed, consisting of prisms, which are only slightly poisonous. The aqueous solution, when boiled, deposits a heavy precipitate of *hydroxymercury propionic anhydride*, $\overline{OHgCH_2CH_2CO}$ (B. **40**, 386).

Dihalogen Propionic Acids.—*αα*-Acids are prepared by the chlorination and bromination of propionic acid (B. **18**, 235); *αβ*-acids, by the addition of chlorine and bromine to acrylic acid, by the addition of a halogen acid to α-halogen acrylic acids, and by the oxidation of the corresponding alcohols (p. 285); *ββ*-acids, by the addition of a halogen acid to β-halogen acrylic acids.

αα-Dichloropropionic Acid, $CH_3CCl_2CO_2H$, b.p. 185–190°; *ethyl ester*, b.p. 156–157°; *chloride*, from pyroracemic acid and PCl_5, b.p. 105–115°, *amide*, m.p. 116° (B. **11**, 388); *nitrile*, b.p. 105° (B. **9**, 1593).

The silver salt changes to *pyroracemic acid* when heated in aqueous solution, and αα-dichloropropionic acid.

αα-Dibromopropionic Acid, m.p. 61°, b.p. 220°; *ethyl ester*, b.p. 190°, is decomposed by sodium hydroxide into pyroracemic acid, $CH_3COCOOH$, and bromacrylic acid (A. **342**, 130).

αβ-Dichloropropionic Acid, $CH_2ClCHClCO_2H$, m.p. 50°, b.p. 210°; *ethyl ester*, b.p. 184°.

αβ-Dibromopropionic Acid, m.p. 51° and 64°, b.p. 227° with partial decomposition, is capable of existing in two allotropic modifications, which can be readily converted one into the other, and of which the more stable possesses the higher melting point. Water or sodium hydroxide produces from it α-bromoacrylic and glyceric acids (A. **342**, 135); *ethyl ester*, b.p. 211–214°.

ββ-Dibromopropionic Acid, m.p. 71°, is formed from β-bromacrylic acid and HBr (B. **27**, R. 257).

Substitution Products of the Butyric Acids.

α-Chloro-n-butyric Acid, $CH_3CH_2CHClCO_2H$, b.p.$_{15}$ 101° (A. **319**, 358), is a thick liquid: *ethyl ester*, b.p. 156–160°; *chloride*, b.p. 129–132°, is obtained from butyryl chloride (A. **153**, 241); *nitrile*, b.p. 142°.

α-Bromobutyric Acid, b.p. 215°, is prepared from butyric acid.

β-Chloro-n-butyric Acid, $CH_3CHCl.CH_2COOH$, b.p.$_{12}$ 99°, is obtained from allyl cyanide, and from solid crotonic acid and HCl; *nitrile*, b.p. 175°.

β-Bromo-n-butyric Acid, m.p. 18°, b.p.$_{16}$ 122°, and *β-Iodo-n-butyric Acid*, m.p. 110° (B. **22**, R. 741; C. 1905, I. 24) have been obtained from crotonic acid and from allylcyanide.

γ-Chloro-n-butyric Acid, $CH_2ClCH_2CH_2CO_2H$, m.p. 16°, b.p.$_{13}$ 115°, is obtained from the nitrile and from trimethylene carboxylic acid and HCl (A. **319**, 363). Trimethylene chlorobromide, $CH_2Cl.CH_2CH_2Br$ and KCN yield *γ-Chlorobutyric Nitrile*, b.p. 189° (A. **319**, 360). Alkali hydroxides convert the nitrile into trimethylene carboxylic acid nitrile (Vol. II.) (C. 1908, I. 1357). The acid is obtained from this, and when distilled at 200° it yields HCl and butyrolactone.

γ-Bromo- and *γ-Iodobutyric* acids, m.p. 33° and 41°, result from butyrolactone (*q.v.*) by the action of HBr and HI (B. **19**, R. 165).

αβ-Dichlorobutyric Acid, $CH_3CHClCHClCO_2H$, m.p. 63°. *αβ-Dibromobutyric Acid*, m.p. 85°. Both are obtained from crotonic acid (p. 295). *βγ-Dibromobutyric Acid* is obtained from vinyl acetic acid (p. 297).

ααβ-Trichlorobutyric Acid, $CH_3.CHCl.CCl_2.CO_2H$, m.p. 60°, appears in the oxidation of trichlorobutyraldehyde and by the action of chlorine on chlorocrotonic acids (B. **28**, 2661).

ααβ-Tribromobutyric Acid, m.p. 115°. The solutions of the sodium salts of both acids break down, when warmed, into CO_2, sodium halide, and αα-dichloro- and αα-dibromopropylene (B. **28**, 2663).

α-Bromisobutyric Acid $(CH_3)_2CBr.COOH$, m.p. 48°, b.p. 199; *ethyl ester*, b.p. 164°; *anhydride*, m.p. 63° (B. **27**, 2951); *amide*, m.p. 148°, with bromine and alkali (comp. p. 277) yields *acetone* (C. 1905, I. 1220).

α-Bromisobutyryl Bromide, b.p. 163°, is converted by zinc in ethereal or ethylacetate *Dimethyl Ketene*, $(CH_3)_2C:CO$. This is a wine-yellow liquid, boiling at a low temperature, which polymerizes at ordinary temperatures to tetramethyl diketo-cyclobutane $[(CH_3)_2C.CO]_2$. It is also obtained from isobutyryl chloride (p. 271) and trimethylamine. Water, alcohol, and aniline unite with the ketone to form isobutyric acid, ester, and anilide respectively (B. **39**, 968).

α-Iodobutyric Acid, m.p. 73° (C. 1900, I. 960), is prepared from isobutyryl chloride, S_2Cl_2, and iodine.

Halogen Substitution Products of the Higher Fatty Acids.

Acids, containing the group $(CH_3)_2CH$, have their methine hydrogen substituted by chlorine when the reaction takes place in sunlight at 100° (C. 1897, II. 1100; 1899, II. 963). Among the higher members some α-bromo-acids are prepared by bromination with or without the presence of phosphorus (B. **25**, 486). Such compounds can also be obtained by the addition of the halogen acids or the halogen to unsaturated acids (A. **319**, 357; C. 1901, I. 93, 665). *Dialkyl bromacetic acids*, $R_2CBrCOOH$, can also be prepared from dialkyl malonic acid by heating with bromine and water. Some of their amides are employed as soporofics (C. 1906, II. 1694).

The dibromo-addition-products of the unsaturated acids have been exhaustively studied. Water almost invariably sets the COOH free from the αβ-dibromides with the formation of brominated hydrocarbons, etc., whereas carbon is never split off from the βγ- and γδ-derivatives, but the first products are brominated lactones, from which hydroxy-lactones and γ-ketonic acids are simultaneously obtained (A. **268**, 55).

B. OLEIC ACIDS, OLEFINE MONOCARBOXYLIC ACIDS, $C_nH_{2n-1}CO_2H$

The acids of this series, bearing the name *Oleic Acids* because oleic acid belongs to them, differ from the saturated fatty acids by containing two atoms of hydrogen less than the latter. They also bear the same relation to them that the alcohols of the allyl series do to the normal alcohols. We can consider them as being derivatives of the alkylens, C_nH_{2n}, produced by the replacement of one atom of hydrogen by the carboxyl group.

Some of the methods employed for the preparation of the unsaturated acids are similar to those used with the saturated acids. Others correspond with the methods used with the olefines, and others, again, are peculiar to this class of bodies.

From compounds containing a like *carbon content:*

(1) Like the saturated fatty acids, they are produced by the oxidation of their corresponding alcohols and aldehydes; thus, allyl alcohol and its aldehyde afford acrylic acid:

$$\underset{\text{Allyl Alcohol.}}{CH_2:CH.CH_2OH} \longrightarrow \underset{\text{Acrolein.}}{CH_2:CH.CHO} \longrightarrow \underset{\text{Acrylic Acid.}}{CH_2:CH.CO_2H.}$$

(2) by the action of alcoholic potassium hydroxide (p. 286) on the monohalogen derivatives of the fatty acids, or by the action of heat on them, together with a tertiary base such as diethyl aniline or quinoline (C. 1898, I. 778).

$$\underset{\text{α-Chlorobutyric Acid.}}{CH_3.CH_2.CHCl.CO_2H} \text{ and } \underset{\text{β-Chlorobutyric Acid.}}{CH_3.CHCl.CH_2.CO_2H} \text{ yield } \underset{\text{Crotonic Acid.}}{CH_3.CH:CH.CO_2H}$$

The β-derivatives are especially reactive, sometimes parting with halogen acids when boiled with water (p. 286); whereas the γ-halogen acids yield hydroxy-acids and lactones. (3) Similarly, the αβ-derivatives of the acids (p. 289) readily lose two halogen atoms, (*a*) either by the action of nascent hydrogen—

$$\underset{\text{αβ-Dibromopropionic Acid.}}{CH_2Br.CHBr.CO_2H} + 2H = \underset{\text{Acrylic Acid.}}{CH_2:CH.CO_2H} + 2HBr,$$

or (*b*) even more readily when heated with a solution of potassium iodide, in which instance the primary di-iodo-compounds part with iodine (p. 136):

$$CH_2I.CHI.CO_2H = CH_2{:}CH.CO_2H + I_2.$$

(4) by the addition of hydrogen to acetylene carboxylic acids:

$$\underset{\text{Tetrolic Acid.}}{CH_3.C\vdots C.COOH} + 2H = \underset{\text{Crotonic Acid.}}{CH_3.CH{:}CH.COOH.}$$

(5) by the removal of water (in the same manner in which the alkylens C_nH_{2n} are formed from the alcohols) from the hydroxy-fatty acids (the acids belonging to the lactic series):

$$\underset{\alpha\text{-Hydroxypropionic Acid.}}{CH_3CH(OH).CO_2H} \text{ and } \underset{\beta\text{-Hydroxypropionic Acid.}}{CH_2(OH).CH_2.CO_2H} \text{ yield } \underset{\text{Acrylic Acid.}}{CH_2{:}CH.CO_2H.}$$

Here again the β-derivatives are most inclined to alteration, losing water when heated. The removal of water from α-derivatives is best accomplished by treating the esters with PCl_3. The esters of the unsaturated acids are formed first, and can be saponified by means of alkalis. Another method is to act with P_2O_5 on the nitriles of the hydroxy-acids (C. 1898, II. 662). β-Hydroxy-acids also yield olefine carboxylic acids when boiled with alkalis (A. **283**, 58).

If both α-situated hydrogen atoms in a β-hydroxy-acid are substituted, warming the ester with P_2O_5 causes elimination of water in the $\beta\gamma$ position; if, however, there is no hydrogen in the γ position, an informal rearrangement occurs which favours the expulsion of water (C. 1906, II. 317, 318):

$$CH_3CH(OH)C(CH_3)CO_2R \xrightarrow{-H_2O} CH_2{:}CHC(CH_3)_2CO_2R$$
$$CH_2(OH)C(CH_3)_2CO_2R \xrightarrow{-H_2O} CH(CH_3){:}C(CH_3)CO_2R.$$

(6) Amino-fatty acids lose the amino-group, after previous methylation, and yield olefine carboxylic acids (B. **33**, 1408).

(7) α-alkyl α-bromethylene succinic acids lose HBr and CO_2 when boiled with sodium hydroxide (C. 1899, I. 1071).

Nucleus-synthetic Methods.—(8) Some may be prepared synthetically from the halogen derivatives, $C_nH_{2n-1}X$, through the cyanides (p. 252); thus, allyl iodide yields allyl cyanide and crotonic acid, and the position of the double bond is changed:

$$CH_2{=}CHCH_2I \longrightarrow CH_2{:}CH.CH_2CN \longrightarrow CH_3CH{=}CHCO_2H.$$

The replacement of the halogen by CN in the compounds $C_nH_{2n-1}X$ is conditioned by the structure of the latter. Although allyl iodide, $CH_2{:}CH.CH_2I$, yields a cyanide, ethylene chloride, $CH_2{:}CHCl$, and β-chloropropylene, $CH_3.CCl{:}CH_2$, are not capable of this reaction.

(9) The action of CO_2 and magnesium on an ethereal solution of allyl bromide produces vinyl acetic acid (B. **36**, 2897):

$$CH_2{:}CHCH_2Br + Mg + CO_2 = CH_2{:}CHCH_2COOMgBr.$$

(10) Some acids have been synthetically prepared by *Perkin's* reaction, which is readily brought about with benzene derivatives, but proceeds with difficulty in the fatty series. It consists in treating the aldehydes with a mixture of acetic anhydride and sodium acetate (comp. Cinnamic Acid):

$$\underset{\text{Œnanthol.}}{C_6H_{13}CHO} + CH_3.CO_2Na = \underset{\text{Nonylenic Acid.}}{C_6H_{13}CH{:}CH.CO_2Na} + H_2O.$$

(A. **277**, 79; C. 1899, I. 595.)

β-Dimethyl acrylic acid is obtained from acetone, malonic acid and acetic anhydride (B. **27**, 1574).

Pyroracemic acid acts analogously with sodium acetate—carbon dioxide splits off and crotonic acid results (B. **18**, 987).

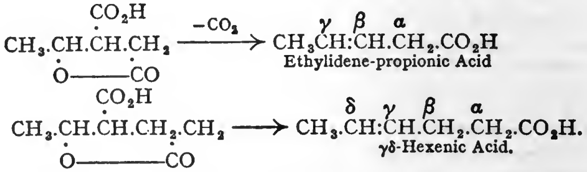
Methods of formation, dependent upon the *breaking-down* of long carbon chains:

(11) by the decomposition of *unsaturated β-ketonic acids*, synthetically prepared by the introduction of unsaturated radicals into acetoacetic esters. Allyl acetoacetic ester yields *allyl acetic acid* (p. 299).

(12) by the decomposition of *unsaturated malonic acids*, containing the two carboxyl groups attached to the same carbon atom (p. 253):

$$\underset{\text{Ethylidene Malonic Acid.}}{CH_3.CH:C(CO_2H)_2} = \underset{\text{Crotonic Acid.}}{CH_3.CH:CH.CO_2H} + CO_2.$$

(13) Unsaturated βγ-acids are prepared by distilling γ-lactone-β-carboxylic acids, the alkylated paraconic acids (B. **23**, R. 91). In the same manner γδ-unsaturated acids result from the δ-lactone-γ-carboxylic acids (B. **29**, 2367):



Methyl Paraconic Acid,

$$\begin{array}{l} \qquad\qquad CO_2H \\ CH_3.CH.CH.CH_2 \\ \qquad O\text{———}CO \end{array} \xrightarrow{-CO_2} \underset{\text{Ethylidene-propionic Acid}}{CH_3\overset{\gamma}{C}H:\overset{\beta}{C}H.\overset{\alpha}{C}H_2.CO_2H}$$

δ-Caprolactone-γ-carboxylic Acid,

$$\begin{array}{l} \qquad\qquad CO_2H \\ CH_3.CH.CH.CH_2.CH_2 \\ \qquad O\text{————}CO \end{array} \longrightarrow \underset{\text{γδ-Hexenic Acid.}}{CH_3.\overset{\delta}{C}H:\overset{\gamma}{C}H.\overset{\beta}{C}H_2.\overset{\alpha}{C}H_2.CO_2H.}$$

Isomerism.—An isomer of acrylic acid is neither known nor possible. The second member of the series has three structurally isomeric, open-carbon chain modifications:

(1) $CH_3.CH{=}CH.CO_2H$; (2) $CH_2{=}CH.CH_2.CO_2H$; (3) $CH_2{=}C{<}\begin{smallmatrix}CO_2H\\CH_3\end{smallmatrix}$.

In fact, there are three crotonic acids—the ordinary *solid crotonic acid, isocrotonic acid* and *methyl acrylic acid.* Formerly, formula 2 was ascribed to isocrotonic acid. There is, however, considerable support for the view that both acids—the ordinary solid crotonic acid and isocrotonic acid—have the same formula. Hence it is assumed that *crotonic* and *isocrotonic acids* are merely geometric, stereo- or space-isomers. (Comp. crotonic acids, p. 295.)

Numerous pairs of isomers, whose differences may be similarly indicated, resemble crotonic and isocrotonic acids—angelic and tiglic acids; oleic and elaïdic acid; erucic and brassidic acids.

The monocarboxylic acids of tri-, tetra-, penta-, and hexamethylene are structurally isomeric with the acids $C_3H_5.CO_2H$, $C_4H_7CO_2H$, $C_5H_9CO_2H$, $C_6H_{11}CO_2H$. Further, the *trimethylene carboxylic acid*, $\begin{smallmatrix}CH_2\\ |\\ CH_2\end{smallmatrix}{>}CH.CO_2H$, is isomeric with the three crotonic acids, and *tetramethylene carboxylic acid*, $CH_2{<}\begin{smallmatrix}CH_2\\CH_2\end{smallmatrix}{>}CHCO_2H$, etc., with the acids $C_4H_7CO_2H$. (Comp. p. 80.)

Properties and Reactions.—Like the saturated acids in their entire character, the unsaturated derivatives are, however, distinguished by their ability to take up additional atoms: they unite the properties of a fatty acid with those of an olefine.

(1) On combining with two hydrogen atoms they become converted into saturated fatty acids.

Most of the lower members combine readily with the H_2 evolved in the action of zinc on dilute sulphuric acid, whilst the higher remain unaffected. Sodium amalgam apparently only reduces those acids in which the carboxyl group is in union with the doubly-linked pair of carbon atoms (B. 22, R. 376). All may be hydrogenized, however, by heating with hydriodic acid and phosphorus.

(2) Esters of the unsaturated acids, such as acrylic and crotonic acids, polymerize under the influence of sodium methoxide, whereby the double bond is broken, and the β-carbon atom of one molecule joins the α-carbon atom of a second, accompanied by a compensating wandering of a hydrogen atom:

$$2CH_2{:}CH.COOH = CO_2H.C({:}CH_2).CH_2.CH_2.COOH.$$

(3) They combine with halogen acids, forming monohalogen fatty acids. In so doing the halogen atom enters the molecule as far as possible from the carboxyl group (p. 285).

(4) They unite with the halogens to form dihalogen fatty acids (p. 285).

All these reactions have already been given as methods for forming fatty acids and their halogen derivatives.

(5) Ammonia converts the olefine carboxylic acids into amino-fatty acids: crotonic acid yields β-aminobutyric acid. Hydrazine and phenylhydrazine behave similarly with the same compounds.

(6) Diazoacetic ester and diazomethane combine with the olefine carboxylic esters to produce pyrazoline carboxylic ester; acrylic ester and diazoacetic ester yield 3,4-pyrazoline carboxylic ester (*q.v.*) (*Buchner*, A. **273**, 222).

(7) The olefine carboxylic acids unite with N_2O_4, forming nitriles of the nitrohydroxycarboxylic acids (C. 1903, II. 554; 1904, I. 260):

$$CH_3CH{:}CHCOOH \xrightarrow{N_2O_4} CH_3CH(ONO).CH.(NO_2)COOH.$$

(8) The behaviour of unsaturated acids towards alkalis is especially noteworthy.

(*a*) When heated to 100°, with KOH or NaOH, they frequently absorb the elements of water and pass into hydroxy acids. Thus, from acrylic acid we obtain α-lactic acid, $CH_2{:}CH.CO_2H + H_2O = CH_3.CH(OH).CO_2H$.

(*b*) βγ-Unsaturated acids rearrange themselves to αβ-unsaturated acids (*Fittig*, A. **283**, 47, 269; B. **28**, R. 140) when they are boiled with alkali hydroxide; the double union is made to take a new position:

$$\underset{\text{Hydrosorbic Acid.}}{\overset{\epsilon}{C}H_3.\overset{\delta}{C}H_2.\overset{\gamma}{C}H=\overset{\beta}{C}H.\overset{\alpha}{C}H_2.COOH} \longrightarrow \underset{\text{n-Butylidene Acetic Acid.}}{\overset{\epsilon}{C}H_3.\overset{\delta}{C}H_2.\overset{\gamma}{C}H_2.\overset{\beta}{C}H=\overset{\alpha}{C}H.COOH.}$$

(*c*) When fused with potassium or sodium hydroxide their double union is severed and two monobasic fatty acids result:

$$\underset{\text{Acrylic Acid.}}{CH_2{:}CH.CO_2H} + 2H_2O = \underset{\text{Formic Acid.}}{CH_2O_2} + \underset{\text{Acetic Acid.}}{CH_3.CO_2H} + H_2.$$

$$\underset{\text{Crotonic Acid.}}{CH_3CH{:}CH.CO_2H} + 2H_2O = \underset{\text{Acetic Acid.}}{CH_3.CO_2H} + \underset{\text{Acetic Acid.}}{CH_3.CO_2H} + H_2.$$

The decomposition occasioned by fusion with alkalis is not a reaction which can be applied in ascertaining constitution, because under the influence of the alkalis there may occur a displacement or rearrangement of the double union.

(9) Oxidizing agents like chromic acid, nitric acid and potassium permanganate have the same effect as alkalis. (*a*) The group linked to carboxyl is usually further oxidized, and thus a dibasic acid results.

(*b*) When carefully oxidized with permanganate, the unsaturated acids undergo an alteration similar to that of the olefines; dihydroxy acids result (*Fittig*, B. **21**, 1887).

$$CH_3.CH{:}C(C_2H_5)CO_2H + O + H_2O = CH_3CH(OH){-}C(OH)(C_2H_5)CO_2H.$$

α-Ethyl Crotonic Acid. α-Ethyl β-Methyl Glyceric Acid.

(10) Ozone produces *ozonides* by action on the olefine carboxylic acids. They are decomposed by water into aldehydes and aldehyde-acids, a reaction which indicates their constitution (comp. p. 84) (A. **343**, 34):

$$CH_3.CH{:}CHCOOH + O_3 + H_2O = CH_3CHO + HOC.COOH + H_2O_2.$$

Crotonic or Isocrotonic Acid. Acetaldehyde. Glyoxylic Acid.

(11) βγ-Unsaturated acids when heated with dilute sulphuric acid yield γ-lactones:

$$(CH_3)_2C{:}CH.CH_2CO_2H \longrightarrow (CH_3)_2C.CH_2.CH_2.COO$$

Pyroterebic Acid. Isocaprolactone.

1. **Acrylic Acid** [*Propene-Acid*], $CH_2{:}CH.CO_2H$, m.p. 7°, b.p. 141°, is obtained according to the general methods:

(1) From β-chloro-, β-bromo-, or β-iodo-propionic acid by the action of alcoholic potassium hydroxide or lead oxide.

(2) From αβ-dibromopropionic acid by the action of zinc and sulphuric acid, or potassium iodide, or reduced copper containing iron (C. 1900, II. 173).

(3) By heating β-hydroxypropionic acid (hydracrylic acid).

The best method consists in oxidizing acroleïn with silver oxide, or by the conversion of acroleïn, by successive treatment with hydrochloric and nitric acid, into β-chloropropionic acid, and the subsequent decomposition of this acid by alkali hydroxide (B. **26**, R. 777; B. **34**, 573).

Acrylic acid is a liquid with an odour like that of acetic acid, and is miscible with water. If allowed to stand for some time, it is transformed into a solid polymer. By protracted heating on the water-bath with zinc and sulphuric acid it is converted into *propionic acid*, a reaction which does not occur in the cold. It combines with bromine to form *αβ-dibromopropionic acid*, and with the halogen acids to yield *β-substitution products* of propionic acid (p. 288). If fused with alkali hydroxides, it is broken up into acetic and formic acids.

The *silver salt*, $C_3H_3O_2Ag$, consists of shining needles; *lead salt*, $(C_3H_3O_2)_2Pb$, crystallizes in long, silky, glistening needles; *ethyl ester*, $C_3H_3O_2.C_2H_5$, b.p. 101°, obtained from the ester of αβ-dibromopropionic acid by means of zinc and sulphuric acid, is a pungent-smelling liquid; *methyl ester*, b.p. 85°, is polymerized by sodium methyoxide to α-methylene glutaric ester (B. **34**, 427).

Acryl chloride, $CH_2{:}CH.COCl$, b.p. 75°; *anhydride* $[CH_2{:}CH.CO]_2O$, b.p.$_{35}$ 97°; *amide*, $CH_2{:}CH.CONH_2$, m.p. 84°; *nitrile, vinyl cyanide*, $CH_2{:}CH.CN$, b.p. 78° (B. **26**, R. 776; C. 1899, II. 662).

Substitution Products.—There are two isomeric forms of mono- and di-substituted acrylic acids.

α-Chloracrylic Acid, $CH_2{:}CCl.CO_2H$, m.p. 64°, results when αβ- and also αα-dichloropropionic acids are heated with alcoholic potassium hydroxide. It combines with HCl at 100° to produce αβ-dichloropropionic acid (B. **10**, 1499; **18**, 244).

β-Chloracrylic Acid, $CHCl{:}CH.CO_2H$, m.p. 84°, is produced together with dichloracrylic acid in the reduction of *chloralide* with zinc and hydrochloric acid

(A. **203,** 83; **239,** 263), also from *propiolic acid*, $C_3H_2O_2$ (p. 303), by the addition of HCl. It unites with HCl to ββ-dichloropropionic acid; *ethyl ester*, b.p. 146°.

a-Bromacrylic Acid, m.p. 69–70°, is slowly decomposed by alkalis into acetylene, alkali bromide, and bicarbonate (A. **342,** 135).

β-Bromacrylic Acid, m.p. 115–116°.

β-Iodoacrylic Acid, is known in two modifications, m.ps. 139–140° and 65° (B. **19,** 542).

aβ-Dichloracrylic Acid, m.p. 87°; *ββ-Dichloracrylic Acid*, m.p. 76–77°.

aβ-Dibromacrylic Acid, m.p. 85–86°; *ββ-Dibromacrylic Acid*, m.p. 86°.

aβ-Di-iodo-acrylic Acid, m.p. 106°; *ββ-Di-iodo-acrylic Acid*, m.p. 133° (B. **18,** 2284).

a-Chlor-β-iodo-Acrylic Acid, m.p. 89°, results from reduction of *Iodoso-chloracrylic Acid*, or *Iodosochloro-chloracrylic Acid*, which in turn is prepared by the action of water or alcohol on *iodosochloro-chlorofumaric acid* (B. **38,** 2842):

$$ClIC(COOH):CCl.COO \longrightarrow ClICH:CCl.COO \longrightarrow ICH.CClCOOH.$$

Iodosochloro-chloro-fumaric Acid. Iodosochloro-chloracrylic Acid. Chloro-iodo-acrylic Acid.

Trichloracrylic Acid, m.p. 76°; *ethyl ester*, b.p. 193°; *orthoethyl ester*, $CCl_2:CClC(OC_2H_5)_3$, b.p. 236°, from hexachloropropylene (A. **297,** 312).

Tribromacrylic Acid, m.p. 117–118°.

2. Crotonic Acids, $C_3H_5.CO_2H$.

In the introduction to the olefine carboxylic acids the isomerism of the crotonic acids was made evident, and it was shown that the difference between crotonic and isocrotonic or quartenylic acid depended on the different arrangement of the atoms in the molecules of the two acids, in the sense of the following formulæ (A. **248,** 281):

$$\begin{matrix}HCCO_2H\\ \|\\ HC.CH_3\end{matrix}$$

(Plane Symmetric Config.)

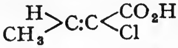
$$\begin{matrix}HC.CO_2H\\ \|\\ CH_3CH\end{matrix}$$

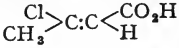
(Axial Symmetric Config.)

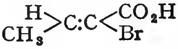
Which of the two formulæ may be assigned to the ordinary solid *crotonic acid*, and which to the lower melting *isocrotonic acid* has not yet been determined with certainty, although there has been no dearth of investigations to place the matter on experimental and theoretical bases (B. **25,** R. 855, 856; **26,** 108; **29,** 1639; **34,** 189; **38,** 2534; A. **268,** 16; **283,** 47; C. 1897, II. 159; J. pr. Ch. [2] **46,** 402; **75,** 105; Z. phys. Ch. **48,** 40).

In the following table of the crotonic acids and their halogen substitution products, the plane-symmetrical or *cis*- configuration has been *arbitrarily* assigned to crotonic acid, and the axial-symmetrical or *cis*- trans (pp. 34, 35) formula to isocrotonic acid.

(1) Crotonic Acid	${}^{CH_3}_{H}\!>C:C<^{CO_2H}_{H}$	m.p. 72°;	b.p. 180°.
(1*a*) a-Chlorocrotonic Acid	${}^{CH_3}_{H}\!>C:C<^{CO_2H}_{Cl}$	,, 99°;	,, 212°.
(1*b*) β-Chlorocrotonic Acid	${}^{CH_3}_{Cl}\!>C:C<^{CO_2H}_{H}$	,, 94°;	,, 200°.
(1*c*) a-Bromocrotonic Acid	${}^{CH_3}_{H}\!>C:C<^{CO_2H}_{Br}$	,, 106°.	
(1*d*) β-Bromocrotonic Acid	${}^{CH_3}_{Br}\!>C:C<^{CO_2H}_{H}$	,, 95°.	
(2) Isocrotonic Acid	${}^{H}_{CH_3}\!>C:C<^{CO_2H}_{H}$	,, 15°;	,, 75° (23 mm.).

(2*a*) **α-Chlorisocrotonic Acid**  $\begin{matrix}H\\CH_3\end{matrix}>C{:}C<\begin{matrix}CO_2H\\Cl\end{matrix}$ m.p. 66°.

(2*b*) **β-Chlorisocrotonic Acid**  $\begin{matrix}Cl\\CH_3\end{matrix}>C{:}C<\begin{matrix}CO_2H\\H\end{matrix}$ „ 59°; b.p. 195°.

(2*c*) **α-Bromisocrotonic Acid**  $\begin{matrix}H\\CH_3\end{matrix}>C{:}C<\begin{matrix}CO_2H\\Br\end{matrix}$ „ 92°.

1. **Ordinary Crotonic Acid** is obtained according to the general methods of formation (pp. 290, 292):

(1) by the oxidation of crotonaldehyde, $CH_3CH:CHCON$ (p. 215);

(2) by the action of alcoholic potassium hydroxide on *α-bromobutyric acid* and *β-iodobutyric acid;*

(3) by the action of KI on *αβ-dibromobutyric acid;*

(4) by the distillation of *β-hydroxybutyric acid;*

(5) by the hydrolysis of allyl cyanide, $CH_2:CHCH_2CN$, produced by alkyl iodide and potassium cyanide, accompanied by an internal rearrangement (B. **21,** R. 494; C. 1903, II. 657).

(6) The most practicable method of obtaining crotonic acid is to heat malonic acid, $CH_2(CO_2H)_2$, with paraldehyde and acetic anhydride: the ethylidene malonic acid first produced decomposes into CO_2 and crotonic acid (p. 291) (A. **218,** 147);

(7) Finally, from isocrotonic acid, dissolved in water or carbon bisulphide, by the action of a trace of bromine, in sunlight.

Crotonic acid crystallizes in fine, woolly needles or in large plates, and dissolves in 12 parts water at 20°. The warm aqueous solution reduces alkaline silver solutions with the formation of a silver mirror. Zinc and sulphuric acid, but not sodium amalgam, convert it into normal butyric acid. It combines with HBr and HI to yield β-bromo- and β-iodobutyric acid, and with chlorine and bromine to form αβ-dichloro- and αβ-dibromobutyric acids. Its methyl ester combines at 180° with sulphur (B. **28,** 1636). It polymerizes under the influence of sodium ethoxide to form α-ethylidene β-methyl glutaric ester (B. **33,** 3323). Crotonic ethyl ester, similarly treated, yields β-ethoxybutyric ester (B. **33,** 3329). When fused with potassium hydroxide, it breaks up into two molecules of acetic acid; nitric acid oxidizes it to acetic and oxalic acids, and potassium permanganate to *dihydroxybutyric acid* (A. **268,** 7), Similarly to isocrotonic acid, crotonic acid is split up by ozone and water into acetaldehyde and glyoxylic acid (p. 294).

Methyl ester, b.p. 121°; *chloride,* b.p. 114° (B. **34,** 191); *anhydride,* b.p.$_{19}$ 128–130°, from crotonic acid and acetic anhydride, gives, with BaO_2, *crotonyl peroxide* $(CH_3CH:CHCO)_2O_2$, m.p. 41 (C. 1903, I. 958).

(1*a*) *α*-**Chlorocrotonic Acid,** $CH_3.CH:CCl.CO_2H$, is obtained when trichlorobutyric acid (p. 289) is treated with zinc and hydrochloric acid, or zinc dust and water; also, by the action of alcoholic potassium hydroxide on αβ-dichlorobutyric ester (B. **21,** R. 243).

(1*b*) **β-Chlorocrotonic Acid,** $CH_3.CCl:CH.CO_2H$, is obtained in small quantities (together with β-chlorisocrotonic acid) from acetoacetic ester, and by the addition of HCl to tetrolic acid. With boiling alkalis it yields tetrolic acid (p. 304). Sodium amalgam converts both α- and β-chlorocrotonic acids into ordinary crotonic acid.

Chlorocrotonic acid, $CH_2Cl.CH:CH.CO_2H$, m.p. 77°, from the *nitrile,* b.p.$_{18}$ 73°, which is prepared by distilling the addition product of HNC and epichlorhydrin with P_2O_5 (C. 1900, II. 37).

(1*c*) *a*-**Bromocrotonic Acid** is prepared from the ester of dibromobutyric acid.

(1*d*) *β*-**Bromocrotonic Acid** is produced from tetrolic acid.

Dichloro- and Dibromocrotonic Acids. (See Tetrolic Acid, p. 304.)

(2) **Isocrotonic Acid,** *Quartenylic acid, Cis-trans Crotonic Acid, Allocrotonic Acid,* m.p. 15°, was first obtained from *β*-chlorisocrotonic acid by means of sodium amalgam, and results also from *α*-chlorisocrotonic acid. It is also formed by distilling *β*-hydroxyglutaric acid under reduced pressure (C. 1898, II. 1011). Heated in a closed tube to 170–180°, it is converted into crotonic acid, a change which also partially occurs during distillation. A further change is brought about by bromine in aqueous or carbon bisulphide solution in sunlight (C. 1897, II. 259). It can be separated from the solid crotonic acid by means of the increased solubility of its sodium salt in alcohol, or its more easily soluble quinine salt in water (C. 1897, II. 260; 1904, I. 167). Melted with potassium hydroxide isocrotonic acid yields only acetic acid, like the ordinary crotonic acid, into which it may first be changed. Sodium amalgam has no action on it. It absorbs HI, forming *β*-iodobutyric acid (B. **22,** R. 741). Chlorine unites with it to form a liquid dichloride, $C_4H_6Cl_2O_2$, the iso-*αβ*-dichlorobutyric acid, which gives up HCl, changing into *α*-chlorocrotonic acid. $KMnO_4$ oxidizes it to *Isodihydroxybutyric acid* (*q.v.*) (A. **268,** 16).

(2*a*) *α*-**Chlorisocrotonic Acid** is obtained by the action of sodium hydroxide on free *αβ*-dichlorobutyric acid. It is the most soluble of the four chlorocrotonic acids (B. **22,** R. 52).

(2*b*) When PCl_5 and water act on acetoacetic ester, $CH_3CO.CH_2COC_2H_5$, *β*-**chlorisocrotonic acid** (with *β*-chlorocrotonic acid) is produced. It is very probable that *β*-dichlorobutyric acid is formed at first, and this afterward parts with HCl. It is also formed by protracted heating of *β*-chlorocrotonic acid.

Sodium amalgam converts both the *α*- and *β*-chlorisocrotonic acids into liquid isocrotonic acid (B. **22,** R. 52).

α-**Bromisocrotonic Acid** is produced by the action of sodium hydroxide on free *αβ*-dibromobutyric acid (B. **21,** R 242).

(3) **Vinyl Acetic Acid,** $CH_2{:}CH.CH_2COOH$, b.p.$_{18}$ 71°, is produced, together with glutaconic acid, by heating *β*-hydroxyglutaric acid; also from *β*-bromo-n-glutaric acid by the action of sodium hydroxide solution; or by heating a solution of its neutral sodium salt. It can further be obtained from allyl bromide, CO_2, and Mg, in ether (B. **36,** 2897). It is an oil, volatile in steam. Boiling with sodium hydroxide converts it into ordinary crotonic acid and *β*-hydroxybutyric acid; acids produce the ordinary crotonic acid only. Bromine changes it into *βγ*-dibromobutyric acid, which gives *β*-hydroxy-*γ*-butyrolactone when boiled with water. *Calcium salt,* $(C_4H_5O_2)_2Ca+H_2O$ (B. **35,** 938), *Vinyl Acetonitrile, Allyl Cyanide,* $CH_2{:}CH.CH_2CN$, b.p. 118°, obtained from allyl bromide or iodide with alkali cyanide, yields solid crotonic acid on hydrolysis, accompanied by internal change. Bromine produces *βγ*-dibromobutyronitrile, which, on saponification, yields *βγ*-dibromobutyric acid; reduction of the latter with zinc and alcohol gives rise to vinyl acetic acid (C. 1905, I. 434).

(4) **Methacrylic Acid,** $CH_2{:}C{<}\begin{matrix}CH_3\\CO_2H\end{matrix}$, m.p. 16°, b.p. 160·5°. Its ethyl ester was first obtained by the action of PCl_3 on hydroxy-isobutyric ester, $(CH_3)_2.C(OH).CO_2.C_2H_5$. It can be prepared from *α*-bromisobutyric acid by warming it with concentrated sodium hydroxide solution (A. **342,** 159). It is, however, best prepared by boiling citrabromopyrotartaric acid (from citraconic acid and HBr) with water or a sodium carbonate solution:

$$C_5H_7BrO_4=C_4H_6O_2+CO_2+HBr.$$

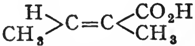
It crystallizes in prisms which are readily soluble in water; it polymerizes on keeping and in contact with HCl to *Polymethacrylic Acid* (B. **30,** 1227). Sodium amalgam easily converts it into isobutyric acid. With HBr and HI it forms *α*-brom- and *α*-iodo-isobutyric acid, whilst bromine produces *αβ*-dibromisobutyric acid, whereby the assumed constitution is substantiated (J. pr. Ch. [2] **25,** 369). Fusion with potassium hydroxide decomposes it into propionic and formic acids. The *nitrile,* b.p. 90°, is produced from acetone cyanhydrin by P_2O_5 (C. 1898, II. 662). *Bromomethacrylic acid* and *Isobromomethacrylic acids,* $BrCH{:}C(CH_3)COOH$, m.ps. 64° and 66°, are produced from citra- and mesodibromopyroracemic acid. They are separated from one another by means of petroleum ether. Heat changes the iso-acid into the normal form, which on further heating is decomposed into HBr, CO_2, and allene (p. 90) (A. **343**, 163).

The characterization of the four crotonic acids can be effected through their *anilides*, $C_3H_5.CO.NHC_6H_5$, which are obtained by treating the acids with PCl_5, aniline, and sodium hydroxide (B. **38**, 254):

Crotonic Anilide, m.p. 118°; *Vinyl Acetic Anilide*, m.p. 58°; *Isocrotonic Anilide*, m.p. 102°; *Methacrylic Anilide*, m.p. 87°.

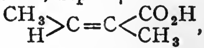
Pentenic Acids, $C_4H_7.CO_2H$.

Of the isomers of this formula, angelic or *αβ*-dimethyl acrylic acid is the most important. It bears the same relation to tiglic acid that was observed with crotonic and isocrotonic acids (p. 295).

2. **Angelic Acid,**  $\genfrac{}{}{0pt}{}{H}{CH_3}{>}C{=}C{<}\genfrac{}{}{0pt}{}{CO_2H}{CH_3}$, m.p. 45°, b.p. 185°, exists free along with valeric and acetic acids in the roots of *Angelica archangelica*, and as butyl and amyl esters, together with tiglic amyl ester, in Roman oil of cumin, the oil of *Anthemis nobilis*.

Angelic acid congeals, when well cooled, and may be thus separated from liquid valeric acid by pressure. Angelic and tiglic acids can be separated by means of the calcium salts, that of the first being very readily soluble in cold water (B. **17**, 2261; A. **283**, 105).

When 10 grams of angelic acid are boiled for twenty hours with sodium hydroxide (40 grams NaOH in 160 grams of water), two-thirds of it are converted into tiglic acid. Heating with water at 120° will change over one-half of it to tiglic acid (A. **283**, 108). When pure angelic acid is heated to boiling for hours it is completely changed to tiglic acid. The same occurs by the action of concentrated sulphuric acid at 100°. It dissolves without difficulty in hot water, and volatilizes readily in steam; *ethyl ester*, b.p. 141°.

Tiglic Acid, *α-Methyl Crotonic Acid*,  $\genfrac{}{}{0pt}{}{CH_3}{H}{>}C{=}C{<}\genfrac{}{}{0pt}{}{CO_2H}{CH_3}$, m.p. 64·5°, b.p. 198°, present in Roman oil of cumin (see above), and in croton oil (from *Croton tiglium*), is a mixture of glycerol esters of various fatty and oleic acids. It can be prepared from *methyl ethyl hydroxy-acetic acid*, $(C_2H_5)C(CH_3)(OH).COOH$, by the abstraction of water. Together with angelic acid it is obtained from hydroxy-pivalic acid, $HO.CH_2C.(CH_3)_2COOH$, by an internal change accompanied by the loss of water, according to mode of formation 5 (p. 291). Also from acetaldehyde and propionic acid, by mode of formation 10 (p. 291).

Ethyl ester, b.p. 152°, is converted by bromine into two *dibromides* (A. **250**, 240; **259**, 1; **272**, 1; **273**, 127; **274**, 99). For their constitution, compare B. **24**, R. 668. The three possible acids, $C_4H_7CO_2H$, with *normal* structure are also known (*Fittig*, A. **283**, 47; B. **27**, 2658). *Propylidene Acetic Acid, αβ-Pentenic acid*, $CH_3.CH_2.CH{:}CH.CO_2H$, m.p. 10°, b.p. 201°, is formed, together with *γ*-hydroxyvaleric acid, on boiling ethylidene propionic acid with sodium hydroxide; as well as from malonic acid, propionic aldehyde and acetic anhydride, together with *βγ*-pentenic acid; *dibromide*, m.p. 56°. *Ethylidene Propionic Acid, β-Pentenic acid*, $CH_3CH{:}CH.CH_2CO_2H$, b.p. 194°, is best prepared by the distillation of methyl paraconic acid (B. **37**, 1997). It is also produced by the reduction of vinyl acrylic acid (p. 305) by sodium amalgam (B. **35**, 2320); *dibromide*, m.p. 65°.

α-Ethyl Acrylic Acid, $CH_2{=}C(C_2H_5)COOH$, m.p. 45°, b.p. 180°, is obtained from *α*-bromo-*α*-ethyl succinic acid. On warming with concentrated sulphuric acid it is partially changed to tiglic acid, partially into CO and methyl ethyl ketone, $CH_3.CO.C_2H_5$ (C. 1905, I. 591). Sulphuric acid produces similar decompositions and changes in the *homologous α-alkyl acrylic acids* (C. 1905, II. 612).

ββ-Dimethyl Acrylic Acid, $(CH_3)_2C{:}CH.CO_2H$, m.p. 70°, is obtained (1) from *β*-hydroxy-isovaleric acid by distillation; (2) from acetone and malonic acid by means of acetic anhydride (B. **27**, 1574); (3) from its ester, produced when *α*-bromisovaleric acid ester is heated with diethylaniline (A. **280**, 252); (4) from mesityl oxide by the breaking-down action of sodium hypochlorite:

$$(CH_3)_2C{:}COCH_3 \xrightarrow{NaClO} (CH_3)_2C{:}CHCOOH + CHCl_3.$$

(C. 1905, II. 614.) The ethyl ester and HNO_3 yield two isomeric mononitro compounds. See B. **29**, R. 956 for its derivatives.

Allyl Acetic Acid, γδ-Pentenic Acid, $CH_2{:}CH.CH_2.CH_2.CO_2H$, b.p. 187°, is obtained on heating allyl malonic acid.

Hexenic Acids, $C_6H_{10}O_2$.

The normal acids belonging to this class are *Hydro-* and *Isohydrosorbic Acids*.

Hydrosorbic Acid, *Propylidene Propionic Acid, βγ-Hexenic Acid*, $CH_3.CH_2.CH{:}CH.CH_2.CO_2H$, b.p. 208°, is obtained from *ethyl paraconic acid*, $CH_3.CH_2.CH.CH(CO_2H)CH_2COO$, according to method 13 (p. 292); hence it is probably a βγ-unsaturated acid. It is the first reduction product of *sorbic acid*, $CH_3CH{:}CH.CH{:}CH.CO_2H$. During the reduction a shifting of the double union occurs. On boiling hydrosorbic acid with sodium hydroxide, it passes into the isomer whose formation one might expect in the reduction of sorbic acid—into **Isohydrosorbic Acid**, or *Butylidene Acetic Acid, αβ-Hexenic Acid*, $CH_3CH_2CH_2CH{:}CHCO_2H$, m.p. 33°, b.p. 216°. It is also prepared, together with a little of the βγ-acid, by heating α-bromocaproic ester with quinoline (B. **24**, 83; **27**, 1998). When its bromine addition product is boiled with water, hydroxy-caprolactone and homolævulinic acid result (A. **268**, 69).

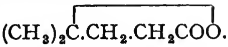
γδ-Hexenic acid, $CH_3CH{:}CH.CH_2CH_2COOH$, m.p. 0°, b.p. 206° (see mode of formation 13, p. 292). Permanganate breaks it down into acetic acid and succinic acid (B. **37**, 1999). *δε-Hexenic acid*, $CH_2{:}CHCH_2CH_2CH_2COOH$, b.p. 203°, is formed, together with the γδ-acid, from α-hydroxy-α-methyl adipic acid by the action of heat; also from *a*-aminocaproic acid by means of nitrous acid (B. **37**, 1999).

Vinyl Dimethyl Acetic Acid, $CH_2{:}CH.C(CH_3)_2COOH$, b.p. 185°. Its ester is obtained from ααβ-trimethyl hydracrylic ester by P_2O_5. The acid is oxidized by permanganate to dimethyl malonic acid, $(CH_3)_2C(COOH)_2$. Analogously many homologous *alkenyl dimethyl acetic acids* can be obtained (C. 1906, II. 317, 1116). Their dibromides are partially decomposed by alkalis in an abnormal manner.

αβ-Isohexenic Acid, β-Isopropyl Acrylic Acid, $(CH_3)_2CH.CH{:}CHCOOH$, b.p. 212°, from β-hydroxycaproic acid or α-bromisocaproic ester (B. **29**, R. 667; C. 1899, I. 1157).

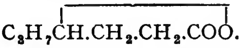
Ethyl Crotonic Acid, $CH_3.CH{:}C(C_2H_5)COOH$, m.p. 40°, and *Ethyl Isocrotonic Acid*, b.p. 200°, are obtained together on the distillation of diethyl glycolic acid, $(C_2H_5)_2C(OH).COOH$. The first is a sublimable solid, the second a liquid. The latter is converted into the solid acid when heated under pressure to 200° (A. **334**, 105). The *calcium salt* of the iso-acid is less soluble in hot water than in cold.

Pyroterebic Acid, $(CH_3)_2C{:}CH.CH_2.CO_2H$, and **Teracrylic Acid**, $C_3H_7.CH{:}CH.CH_2.CO_2H$, b.p. 218° (A. **208**, 37, 39), belong to the acids $C_6H_{10}O_2$ and $C_7H_{12}O_2$. They deserve notice because of their genetic connection with two oxidation products of turpentine oil—*terebic acid* and *terpenylic acid*—which will be considered in Vol. II. Pyroterebic acid is changed by protracted boiling or by HBr to isomeric isocaprolactone:



$$(CH_3)_2C.CH_2.CH_2COO.$$

Teracrylic acid is converted by HBr into the isomeric *heptolactone*:



$$C_3H_7CH.CH_2.CH_2.COO.$$

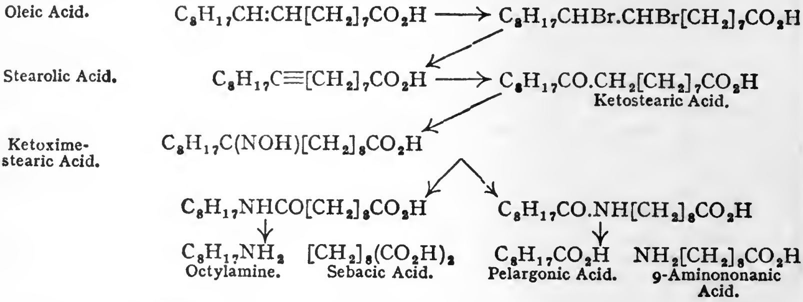
Nonylenic Acid, $CH_3(CH_2)_5CH{:}CH.CO_2H$, from œnanthol by general method of formation 10, p. 291.

Decylenic Acid, $C_6H_{13}.CH{=}CH.CH_2.CO_2H$, is formed from hexyl paraconic acid, according to general method of formation 11, p. 292.

Undecylenic Acid, $CH_2{=}CH(CH_2)_8CO_2H$, m.p. 24·5°, b.p.$_{15}$ 165°, is produced, together with œnanthol (p. 201) (C. 1901, I. 612) by distilling castor oil under reduced pressure. It yields *sebacic acid*, $(CH_2)_8(CO_2H)_2$ (*q.v.*), on oxidation (B. **19**, R. 338; **19**, 2224). *Chloride*, b.p.$_{14}$ 128°; *anhydride*, m.p. 13°, b.p.$_{11}$ 170°; *nitrile*, b.p.$_{14}$ 130° (B. **33**, 3580); *amide*, m.p. 85° (B. **31**, 2349). When its *dibromide*, m.p. 38°, is incompletely decomposed by alcoholic potassium hydroxide, *Dehydro-undecylenic Acid*, $CH{\equiv}C[CH_2]_8CO_2H$, m.p. 43°, is obtained, which, fused at 180° with potassium hydroxide, changes to *Undecolic Acid*, $CH_3.C{:}C[CH_2]_7CO_2H$, m.p. 59° (B. **29**, 2232).

Higher Olefine Monocarboxylic Acids.

To ascertain the point of the doubly linked carbon atoms in the higher olefine monocarboxylic acids, the latter are converted into their corresponding acetylene monocarboxylic acids (p. 302), which, in turn, are oxidized and split open at the point of triple carbon union; or they are changed to ketone carboxylic acids, and these are then broken down. Thus, oleic acid yields *stearolic acid*, which may be oxidized to *azelaic acid*, $C_7H_{14}(CO_2H)_2$, and *pelargonic acid*, $C_8H_{17}CO_2H$, This would mean that in stearolic acid the carbon atoms 9 and 10 are united by three bonds, and that they are the atoms which in oleic acid are in double union. This conclusion is confirmed by the conversion of stearolic acid, by means of concentrated sulphuric acid, into *ketostearic* acid, whose oxime undergoes the *Beckmann rearrangement* at 400°, as the result of the action of concentrated sulphuric acid. Two acid amides result, which are decomposed by fuming hydrochloric acid, the one into octylamine and sebacic acid, the other into pelargonic acid and 9-aminononanic acid (B. **27**, 172):



Oleic Acid. $C_8H_{17}CH{:}CH[CH_2]_7CO_2H \longrightarrow C_8H_{17}CHBr.CHBr[CH_2]_7CO_2H$

Stearolic Acid. $C_8H_{17}C{\equiv}[CH_2]_7CO_2H \longrightarrow C_8H_{17}CO.CH_2[CH_2]_7CO_2H$ Ketostearic Acid.

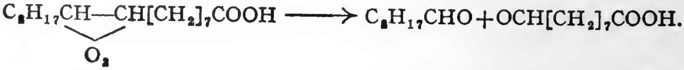
Ketoxime-stearic Acid. $C_8H_{17}C(NOH)[CH_2]_8CO_2H$

$C_8H_{17}NHCO[CH_2]_8CO_2H$ $\qquad$ $C_8H_{17}CO.NH[CH_2]_8CO_2H$

$C_8H_{17}NH_2$ Octylamine. $\quad [CH_2]_8(CO_2H)_2$ Sebacic Acid. $\quad C_8H_{17}CO_2H$ Pelargonic Acid. $\quad NH_2[CH_2]_8CO_2H$ 9-Aminononanic Acid.

The constitution of hypogæic and erucic acids has been determined in the same manner.

The constitution of stearolic acid still remained doubtful, however, since ketostearic acid, $C_{18}H_{17}CO[CH_2]_8COOH$, could also be formed from an acid of the formula $C_7H_{15}C{\equiv}C[CH_2]_8COOH$. However, the assumed constitution of oleic acid was substantiated by boiling its *ozonide* with water, whereby the decomposition products, nonyl aldehyde and azelaïc aldehyde acid, were obtained together with their oxidation products, pelargonic acid and azelaïc acid (B. **39**, 3732):



$$\underbrace{C_8H_{17}CH{-}CH}_{O_3}[CH_2]_7COOH \longrightarrow C_8H_{17}CHO + OCH[CH_2]_7COOH.$$

Hypogæic Acid, $CH_3[CH_2]_7CH{:}CH[CH_2]_5CO_2H$, m.p. 33°, b.p.$_{15}$ 236°, found as glycerol ester in earthnut oil (from the fruit of *Arachis hypogæa*), crystallizes in needles. It results when stearolic acid is fused with KOH at 200° (B. **27**, 3397).

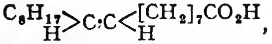
Oleic Acid, $\begin{matrix}C_8H_{17}\\H\end{matrix}{>}C{:}C{<}\begin{matrix}H\\ [CH_2]_7CO_2H\end{matrix} = C_{18}H_{34}O_2$, m.p. 14°, b.p.$_{10}$ 223°, occurs as glycerol ester (*triolein*) in nearly all fats, especially in the oils, as olive oil, almond oil, cod-liver oil, etc. It is obtained in large quantities as a by-product in the manufacture of stearic acid (p. 264).

In preparing oleic acid, olive or almond oil is saponified with potassium hydroxide and the aqueous solution of the potassium salts precipitated with lead acetate. The lead salts which separate are dried and extracted with ether, when lead oleate dissolves, leaving as insoluble the lead salts of all other fatty acids. The ethereal solution is mixed with hydrochloric acid, the lead chloride is filtered off, and the liquid is concentrated. The acid obtained in this way may be fractionated by distillation under strongly diminished pressure.

Oleic acid in a pure condition is odourless, and does not redden litmus. On exposure to the air it oxidizes, becomes yellow, and acquires a rancid odour. Nitric acid oxidizes it with formation of all the lower fatty acids from *capric* to *acetic*, and at the same time dibasic acids, like *sebacic* acid, are produced. A permanganate solution oxidizes it to *azelaïc* acid, $C_9H_{16}O_4$. Moderated oxidation produces dihydroxystearic acid, m.p. 136° (C. 1898, I. 176, 629; 1899, I. 1068).

It unites with bromine to form liquid dibromostearic acid, $C_{18}H_{34}Br_2O_2$, which is converted by alcoholic KOH into *monobromoleic acid*, $C_{18}H_{33}BrO_2$, and then into stearolic acid (p. 304). Reduction by hydrogen and finely divided nickel (C. 1903, I. 1199), or by electrolytic methods (C. 1905, II. 305) converts oleic acid into stearic acid.

Oleic Anhydride, m.p. 28° (C. 1899, I. 1070); *chloride*, b.p.$_{18}$ 213° (B. **33**, 3584).

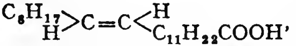
Elaïdic Acid,  $\frac{C_8H_{17}}{H}>C:C<\frac{[CH_2]_7CO_2H}{H}$, m.p. 51°, b.p.$_{10}$ 225°, results from the action of nitrous acid on oleic acid. Oxidation with $KMnO_4$ produces a *dihydroxystearic acid*, m.p. 99° (C. 1899, I. 1068). *Elaïdic Bromide*, m.p. 27°, is reconverted into the acid by sodium amalgam; *chloride*, b.p.$_{13}$ 216°; *anhydride*, m.p. 50°; *nitrile*, b.p.$_{16}$ 214° (B. **33**, 3582); *amide*, m.p. 90° (C. 1899, I. 1070).

Iso-oleic Acid, $C_{18}H_{34}O_2$, m.p. 44–45°, is obtained from the HI-addition product of oleic acid—iodostearic acid—by treatment with alcoholic potassium hydroxide; or from hydroxystearic acid, formed from oleic acid by the action of concentrated sulphuric acid, by distillation under reduced pressure (B. **21**, R. 398; **21**, 1878; **27**, R. 576).

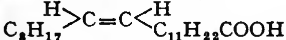
Hydriodic acid reduces oleic and elaïdic acids to *stearic acid*. Oleic, elaïdic, and iso-oleic acids, when fused with potassium hydroxide, break down into *palmitic acid* and *acetic acid*. This is, however, a reaction that cannot be accepted as proving that the double union in the three acids holds the same position. The common view is that oleic and elaïdic acids are stereoisomers, and that iso-oleic is a structural isomer of the other two acids.

Bromine converts the three acids into three different *dibromostearic acids*. Carefully oxidized with potassium permanganate, they yield three different *dihydroxy-stearic acids*.

Δ^2-Oleic Acid, $CH_3[CH_2]_{14}CH.CHCOOH$, m.p. 59, is prepared from α-iodostearic acid and alcoholic potassium hydroxide. Potassium permanganate produces 2,3-*Dihydroxystearic Acid*, m.p. 120°, and subsequently palmitic acid (C. 1906, I. 819).

Erucic Acid,  $\frac{C_8H_{17}}{H}>C=C<\frac{H}{C_{11}H_{22}COOH}$, m.p. 33–34°, b.p.$_{10}$ 254·5°, occurs as its glyceride in rape-seed oil (*Brassica campestris*), in the fatty oil of mustard seed, and in grape-seed oil. By oxidation, erucic acid yields nonylic acid and brassylic acid (B. **24**, 4120; **25**, 961, 2667; **26**, 639, 838, 1867, R. 795, 811); *anhydride*, m.p. 47–50° (C. 1899, I. 1070).

Isoerucic Acid, see B. **27**, R. 166, 577.

Brassidic Acid,  $\frac{H}{C_8H_{17}}>C=C<\frac{H}{C_{11}H_{22}COOH}$, m.p. 66°, b.p.$_{10}$ 256°, is prepared from erucic acid by the action of nitrous acid (B. **19**, 3320) and is to erucic acid what elaïdic acid is to oleic.

Linoleic and ricinoleic acids, although not belonging to the same series, yet closely resemble oleic acid. The first is a simple, unsaturated acid, the second an unsaturated hydroxy-acid.

Linoleic Acid, *Linolic Acid*, $C_{18}H_{32}O_2$, occurs as its glyceride in *drying oils*, which quickly oxidize in the air, become covered with a skin, and then solidify—*e.g.* linseed oil, hemp oil, poppy oil, and nut oil. In the *non-drying* oils—olive oil, rape oil from *Brassica campestris*, rape oil from *Brassica rapa*, almond oil, fish oil, etc.—the oleic glycerol ester occurs.

Various hydroxy-fatty acids are produced when linoleic acid is oxidized with potassium permanganate. From the fact that they can be formed, it has been concluded that certain other acids exist in the crude linoleic acid (B. **21**, R. 436 and 659). On *Oleomargoric Acid*, as a stereoisomer of linolic acid, obtained from Japanese wood oil, see, C. 1903, II. 657.

Ricinoleic Acid, $C_{18}H_{34}O_3 = CH_3[CH_2]_5.CHOH.CH_2CH{:}CH(CH_2)_7$-$CO_2H, [a]_D = +6{\cdot}67°$ (B. **27**, 3471), is present in castor oil in the form of a glyceride, $[\alpha]_D = +3°$. The lead salt is soluble in ether. Subjected to dry distillation, ricinoleic acid splits into *œnanthol*, $C_7H_{14}O$, and *undecylenic acid*, $C_{11}H_{20}O_2$.

Fused with potassium hydroxide, it changes to *sebacic acid*, $C_8H_{16}(CO_2H)_2$, and *sec.-octyl alcohol*, $(C_6H_{13})CHOH.CH_3$. It combines with bromine to form a solid *dibromide*. When heated with HI (iodine and phosphorus), it is transformed into iodoleic acid, $C_{18}H_{33}IO_2$, which yields stearic acid when heated with zinc and hydrochloric acid (B. **29**, 806).

The point of double union between the carbon atoms in ricinoleic acid is ascertained as in the case of oleic acid:

(1) By conversion into *ricinostearolic acid*, m.p. 53°, (2) and this into *keto-hydroxystearic acid*, m.p. 84°, (3) finally, by the breaking down of the oxime of the latter acid (B. **27**, 3121; C. 1900, II. 37).

Nitrous acid converts ricinoleic acid into isomeric *ricinelaïdic acid*, m.p. 53° C. (see B. **21**, 2735; **27**, R. 629).

Alkyl ester and *Acyl derivatives* (B. **36**, 781).

Rapinic Acid, $C_{18}H_{34}O_2$, occurs as glycerol ester in rape oil (B. **29**, R. 673).

Unsaturated Acids, $C_nH_{2n-3}CO_2H$.

The acids of this series contain either a trebly linked pair of carbon atoms, *e.g.* like *acetylene* (p. 86), or two doubly linked pairs of carbon atoms, as in the *diolefines*. They are, therefore, distinguished as acetylene monocarboxylic acids: *propiolic acid series* and *diolefine monocarboxylic acids.*

C. ACETYLENE CARBOXYLIC ACIDS

Methods of Formation.—(1*a*) By the action of alcoholic potassium hydroxide on the brom-addition products of the oleic acids, and (*b*) the monohalogen substitution products of the oleic acids. This is similar to the formation of the acetylenes from the di-halogen substitution products of the paraffins and the mono-halogen substitution products of the olefines.

(2) From the sodium derivatives of the mono-alkyl acetylenes by the action of CO_2:

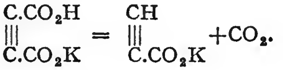
$$CH_3.C{\equiv}CNa + CO_2 = CH_3C{\equiv}C.CO_2Na.$$

Like the acetylenes, they are capable of taking up 2 and 4 monovalent atoms.

The addition of the constituents of water at the treble bond converts these substances into keto-acids. Like the β-keto-acids (*q.v.*) the αβ-acetylene carboxylic acids (alkyl propiolic acids) lose CO_2 on heating and become converted into acetylenes. Boiling with aqueous alkalis produces intermediate β-keto-acids, which break up into ketones and alkali carbonates (comp. C. 1903, II. 487, etc.).

Ammonia converts alkyl propiolic esters into *amides*, which give up water to phosphoric anhydride, forming *nitriles*. Primary and secondary amines when added on to the molecule form *β-amino-acrylic acids;* hydrazines form pyrazolons. A solution of sodium alcoholate or alcoholic potassium hydroxide, acting on esters or nitriles, produce derivatives of *β-alkoxyacrylic acids* or *β-acetal carboxylic acid*, $RC(OC_2H_5){:}CHCOOH$ and $RC(OC_2H_3)_2.CH_2COOH$ (C. 1904, I. 659; 1906, I. 651, 912, 1095; 1907, I. **25**, 738).

Propiolic Acid, *Propargylic Acid* [Propine-Acid], $CH{:}C.CO_2H$, m.p. 6°, b.p. 144°, with decomposition, corresponds with propargyl alcohol (p. 125). The *potassium salt*, $C_3HO_2K+H_2O$, is produced from the primary potassium salt of acetylene dicarboxylic acid, when its aqueous solution is heated:



$$\begin{array}{c} C.CO_2H \\ ||| \\ C.CO_2K \end{array} = \begin{array}{c} CH \\ ||| \\ C.CO_2K \end{array} + CO_2.$$

similarly to the production of acetic acid from malonic acid (p. 256).

The aqueous solution of the salt is precipitated by ammoniacal silver and cuprous chloride solutions, with formation of explosive metallic derivatives. By prolonged boiling with water the potassium salt is decomposed into acetylene and potassium carbonate.

Free propiolic acid, liberated from the potassium salt, is a liquid with an odour resembling that of glacial acetic acid. It dissolves readily in water, alcohol, and ether, and reduces silver and platinum salts. Exposed to sunlight out of contact with the air it polymerizes to trimesic acid:

$$3C_2H.CO_2H = C_6H_3(CO_2H)_3.$$

Sodium amalgam converts it into propionic acid. It forms β-halogen acrylic acids with the halogen acids (p. 294) (B. **19**, 543), and with the halogens yields αβ-dihalogen-acrylic acids.

Ethyl Ester, b.p. 119°. With ammoniacal cuprous chloride it unites to a stable yellow-coloured compound. Zinc and sulphuric acid reduce it to ethyl propargylic ester (p. 129) (B. **18**, 2271).

Chloropropiolic Acid, $CCl{\equiv}C.CO_2H$, is produced from *dichloracrylic acid* (p. 295), and *Bromopropiolic Acid,* C_3BrHO_2, from *mucobromic acid*. *Iodopropiolic Acid,* m.p. 140°, is obtained by saponifying its *ethyl ester,* m.p. 68°, which may be prepared from the Cu compound of propiolic ester by the action of iodine.

The three acids decompose readily into carbon dioxide and spontaneously inflammable *chloracetylene,* $CCl{\equiv}CH$, *bromacetylene* and *iodoacetylene*. The addition of halogen acids leads to ββ-dihalogen acrylic acids, whilst the halogens give rise to *trihalogen acrylic acids*.

Carbon dioxide converts the sodium compounds of the corresponding alkyl acetylenes into the following homologues of propiolic acid (B. **12**, 853; J. pr. Ch. [2] **37**, 417; B. **33**, 3586): the same result is obtained with chlorocarbonic esters (C. 1901, I. 1148; 1903, I. 824; II. 487):

$$RC{\equiv}CNa + ClCO_2C_2H_5 \longrightarrow RC{\equiv}CCO_2C_2H_5 + NaCl.$$

		M. P.	B. P.
Tetrolic Acid, *Methyl Acetylene Carboxylic Acid*	$CH_3C{\equiv}C.CO_2H$	76°	203°
Ethyl Acetylene Carboxylic Acid	$CH_3.CH_2.C{\equiv}C.CO_2H$	80°	—
n-Propyl Acetylene Carboxylic Acid	$CH_3.CH_2.CH_2.C{\equiv}C.CO_2H$	27°	125° (20 mm.)
Isopropyl Acetylene Carboxylic Acid	$(CH_3)_2CH.C{\equiv}C.CO_2H$	38°	107° (20 mm.)
n-Butyl Acetylene Carboxylic Acid	$CH_3.[CH_2]_3C{\equiv}C.CO_2H$	liquid	136° (20 mm.)
tert. Butyl Acetylene Carboxylic Acid	$(CH_3)_3C.C{\equiv}C.CO_2H$	48°	110° (10 mm.)
Amyl Propiolic Acid	$C_5H_{11}C{\equiv}C.CO_2H$	5°	149° (20 mm.)
Hexyl Propiolic Acid	$C_6H_{13}C{\equiv}C.CO_2H$	−10°	155° (18 mm.)
Heptyl Propiolic Acid	$C_7H_{15}C{\equiv}C.CO_2H$	6–10°	166° (20 mm.)
Nonyl Propiolic Acid	$C_9H_{19}C{\equiv}C.CO_2H$	30°	—
Tetradecyl Propiolic Acid	$CH_3[CH_2]_{13}C{\equiv}C.CO_2H$	44°	—

Of these, **Tetrolic Acid** has been the most thoroughly investigatcd, and is obtained from β-chlorocrotonic acid and β-chlorisocrotonic acid when these are boiled with potassium hydroxide (A. **345**, 103). At 210° the acid decomposes into CO_2 and allylene, C_3H_4 (B. **27**, R. 751). Potassium permanganate oxidizes it to acetic and oxalic acids. It combines with HCl and HBr, forming β-chlorocrotonic acid and β-bromocrotonic acid (B. **22**, R. 51 ; **21**, R. 243). With bromine, in sunlight, it yields *dibromocrotonic acid*, m.p. 120°, whereas in the dark the halogen produces the isomeric *dibromocrotonic acid*, m.p. 94° (B. **28**, 1877 ; **34**, 4216). *ααβ*-Trichlorobutyric acid (p. 289), upon the loss of HCl, yields two *dichlorocrotonic acids*, m.p. 75° and 92° (B. **28**, 2665). These two acids are also produced when chlorine acts on tetrolic acid.

Tetrolic Ethyl Ester, b.p. 164°, forms the *amide*, m.p. 148°, with ammonia, together with β-aminocrotonic ester. An aqueous solution of the amide, when heated with mercuric chloride, becomes hydrated, forming acetoacetic amide:

$$CH_3C{\equiv}CCONH_2 \longrightarrow CH_3CO.CH_2CONH_2,$$

Phenylhydrazine forms the tetrolic ester, *phenyl methyl pyrazolone ;* diazoacetic ester produces a *pyrazole* derivative (A. **345**, 100).

Several higher homologues of propiolic acid have been prepared by the action of alcoholic potassium hydroxide on the brom-addition products of the higher olefine monocarboxylic acids (p. 300).

Undecolic Acid, $CH_3C{:}C[CH_2]_7CO_2H$, m.p. 59°, is obtained from *undeclyenic acid* (p. 299). By oxidation, azelaic acid is formed (B. **33**, 3571). Isomeric with it is dehydro-undecylenic acid (p. 299). **Stearolic Acid,** $C_8H_{17}C{:}C[CH_2]_7CO_2H$, m.p. 48° (constitution, see p. 300), is obtained from oleic and elaïdic acids. **Behenolic Acid,** $C_{22}H_{40}O_2$, m.p. 57·5° (constitution, see p. 300), from the bromides of erucic and brassidic acids (B. **24**, 4116 ; **26**, 640, 1867). On warming the last two acids with fuming nitric acid they yield the monobasic acids: *stearoxylic*, or 9,10-*diketostearic acid*, $CH_3[CH_2]_7CO.CO[CH_2]_7CO_2H$, m.p. 86°, and *behenoxylic*, or 13,14-*diketobehenic acid*, $CH_3[CH_2]_7CO.CO.[CH_2]_{11}CO_2H$, m.p. 96° (B. **28**, 276).

Sulphuric acid converts stearolic acid into ketostearic acid, and behenolic acid into ketobrassidic acid (B. **26**, 1867), whose oximes are then converted by the sulphuric acid into $C_8H_{17}CO.NH[CH_2]_8CO_2H$ (p. 300). (Oxidation, comp. Erucic and Brassidic Acids, p. 301.)

D. DIOLEFINE CARBOXYLIC ACIDS

$\Delta^{2,4}$-Diolefine carboxylic acids are obtained by the two following general methods:—

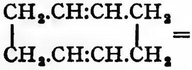
(1) By the condensation of *αβ*-olefine aldehydes with malonic acid, by means of pyridine (B. **35**, 1143).

$$CH_2{:}CH.CHO+CH_2(COOH)_2 \xrightarrow{C_5H_5N} CH_2{:}CH.CH{:}CHCOOH+H_2O+CO_2.$$

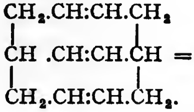
(2) By the condensation of olefine aldehydes or ketones by means of halogen fatty acid esters and zinc, and subsequently splitting off water from the *β*-hydroxy-olefine carboxylic esters thus formed, by heating with alkalis (B. **35**, 3633; **36**, 15, C. 1903, II. 555):

$$\begin{aligned}CH_3CH{:}CH.CHO+BrZnCH_2CO_2R &\longrightarrow CH_3CH{:}CH.CH(OH)CH_2COOR\\ &\longrightarrow CH_3CH{:}CH.CH{:}CH.COOH.\end{aligned}$$

Some of these acids are polymerized by barium hydroxide to di- and tri-molecular modifications which give up CO_2, forming the corresponding cyclic or trimolecular hydrocarbons (B. **35**, 2129) containing an eight-membered ring; *e.g.* from *β*-vinyl acrylic acid:



$$\begin{array}{l}CH_2.CH{:}CH.CH_2\\ |\qquad\qquad\quad\ |\\ CH_2.CH{:}CH.CH_2\end{array} = \text{Cyclo-octadiene}$$



$$\begin{array}{l}CH_2.CH{:}CH.CH_2\\ |\qquad\qquad\quad\ |\\ CH\ .CH{:}CH.CH\\ |\qquad\qquad\quad\ |\\ CH_2.CH{:}CH.CH_2.\end{array} = \text{Dicyclo-dodecatriene}$$

Butadiene Carboxylic Acid, $CH_2{:}CH.CH{:}CHCO_2H$, m.p. 102°, is formed, together with ethylidene propionic acid (p. 298), by the reduction of *Perchlorobutadiene Carboxylic Acid*, $CCl_2{:}CCl.CCl{:}CCl.CO_2H$, m.p. 97°, and *Perchlorobutine Carboxylic Acid*, $CCl_3.C{:}C.CCl_2.CO_2H$, m.p. 127°. These are products of decomposition resulting from the two hexachloro-R-pentenes (Vol. II.) on treatment with alkali (B. **28**, 1644).

β-Vinyl Acrylic Acid, $CH_2{:}CH.CH{:}CHCOOH$, m.p. 80°, is produced by condensing malonic acid and acroleïn in the presence of pyridine, and boiling the resulting product with water. Reduction by sodium amalgam brings about addition at the 1,4 bonds (p. 90), forming *αβγ*-pentenic acid (p. 298). Oxidation with permanganate converts it into racemic acid (B. **35**, 1136). It is isomeric with butadiëne carboxylic acid, towards which it may stand in the same relation as fumaric acid to maleic acid (private information from *Herr Doebner*).

Sorbic Acid, $CH_3CH{=}CH.CH{=}CH.COOH$, m.p. 134·5°, b.p. 228°, is obtained, together with malic acid, from the oil in the unripe juice of the berries of mountain ash (*Sorbus aucuparia*) (1859, *A. W. Hofmann*, A. **110**, 129). It exists there in the form of a lactone, the so-called *parasorbic acid* (*q.v.*), which is boiled with sodium hydroxide or hydrochloric acid (B. **27**, 351). Synthetically, it is prepared from croton aldehyde and malonic acid with pyridine (*Doebner*, B. **33**, 2140), also from *β*-hydroxy-*γδ*-hexenic acid, by boiling it with a 20 per cent. barium hydroxide solution (B. **35**, 3636). Oxidation by $KMnO_4$ produces aldehyde and racemic acid (*q.v.*), a reaction which reveals the structure of sorbic acid (B. **23**, 2377; **24**, 85):

$$\underset{\text{Sorbic Acid.}}{CH_3CH{=}CH.CH{=}CH.COOH}+H_2O+4O=CH_3CHO+\underset{\text{Racemic Acid.}}{COOH(CHOH)_2COOH.}$$

Sodium amalgam converts it into *Hydrosorbic acid* (p. 299). Heated with ammonia, sorbic acid yields a diaminocaproic acid; hydroxylamine brings about a peculiar reaction resulting in acetyl acetone dioxime (p. 355) (B. **37**, 3316). *Sorbic Ethyl Ester*, b.p. 95°, *a-Methyl Sorbic Acid*, m.p. 91°, *a-Ethyl Sorbic Acid*, b.p. 76°, and *βδ-Dimethyl Sorbic Acid*, m.p. 93°, are obtained by method 2 (above).

γε-Dimethyl Sorbic Acid, b.p.$_{20}$ 165°, is prepared according to method 1 (p. 305) from α-methyl β-ethyl acrolein and malonic acid.

Diallyl Acetic Acid, $(CH_2{:}CH.CH_2)_2CH.CO_2H$, b.p. 227°, is obtained from ethyl-diallyl acetoacetate and diallyl malonic acid. Nitric acid oxidizes it to tricarballylic acid, $(CO_2H.CH_2)_2CHCO_2H$.

Geranic Acid belongs to the class of olefine dicarboxylic acids. It will be described together with the olefine terpene bodies (Vol. II.).

IV. DIHYDRIC ALCOHOLS OR GLYCOLS, AND THEIR OXIDATION PRODUCTS

The monohydric alcohols, with their oxidation products,—the aldehydes, the ketones, and the monocarboxylic acids, with their derivatives,—were discussed in the preceding section.

Closely allied to these are the *dihydric alcohols* or *glycols*, and such compounds as may be considered oxidation products of the glycols.

The glycols are derived from the hydrocarbons by the replacement of two hydrogen atoms attached to two different carbon atoms by two hydroxyls. In the case of the monohydric alcohols we distinguished three classes—primary, secondary, and tertiary alcohols. With the *glycols* the classes are twice as numerous. The compounds, which may be considered as oxidation products of the glycols, contain either *two similar*, reactive, atomic groups—*e.g.:*

the *dialdehydes* (*glyoxal*, CHO.CHO),
the *diketones* (*diacetyl*, $CH_3CO.COCH_3$),
the *dicarboxylic acids* (*oxalic acid*, COOH.COOH),

and therefore exhibit double the typical properties of the oxidation products of the monohydric alcohols—compounds of *double function;* or they contain *two* different reactive atomic groups in the same molecule, and have, therefore, the typical properties of different families of compounds. The following bodies have such a *mixed function:*

Aldehyde Alcohols (*Glycolyl Aldehyde*, $CH_2OH.CHO$).
Ketone Alcohols (*Acetyl Carbinol*, $CH_2OH.COCH_3$).
Aldehyde Ketones (*Pyroracemic Aldehyde*, $CH_3.CO.CHO$).
Alcohol Acids or *Hydroxyacids* (*Glycollic Acid*, $CH_2.OH.COOH$).
Aldehydic Acids (*Glyoxylic Acid*, $CHO.CO_2H$).
Ketonic Acids (*Pyroracemic Acid*, $CH_3.CO.COOH$).

Four classes—alcohols, aldehydes, ketones, and monocarboxylic acids—occur with the monohydric alcohols and their oxidation products, whilst in the case of the dihydric alcohols and their oxidation products *ten* classes of derivatives are known. The successive series in which these ten classes will be discussed readily follow, if their systematic interdependence be developed similarly to that of the univalent alcohols and their oxidation products.

MONOHYDRIC ALCOHOLS AND THEIR OXIDATION PRODUCTS.

1*a*. Primary Alcohols.
1*b*. Secondary Alcohols.
1*c*. Tertiary Alcohols.
2. Aldehydes.
3. Ketones.
4. Monocarboxylic Acids.

DIHYDRIC ALCOHOLS AND THEIR OXIDATION PRODUCTS.

1*a*. **Diprimary Glycols.**	2*a*. prim. **Hydroxyaldehydes.** 4. **Dialdehydes.**	7*a*. prim. **Hydroxycarboxylic Acids.** 8. **Aldehydocarboxylic Acids.** 10. **Dicarboxylic Acids.**
$CH_2.OH$ · $CH_2.OH$ Glycol.	CHO · CH_2OH Glycolyl Aldehyde. CHO · CHO Glyoxal.	COOH · $CH_2.OH$ Glycollic Acid. CO_2H · CHO Glyoxylic Acid. COOH · COOH Oxalic Acid.
1*b*. Prim. sec. Glycols.	2*b*. sec. **Hydroxyaldehydes.** 3*a*. prim. **Hydroxyketones.** 5. **Aldehydketones.**	7*b*. sec. Hydroxycarboxylic Acids. 9. **Ketone Carboxylic Acids.** 7*c*. tert. Hydroxycarboxylic Acids.
1*c*. Prim. tert. Glycols.	2*c*. tert. Hydroxyaldehydes.	
1*d*. Disec. Glycols.	3*b*. sec. Hydroxyketones. 6. **Diketones.**	
1*e*. Sec. tert. Glycols.	3*c*. tert. Hydroxyketones.	
1*f*. Ditert. Glycols.		

The dihydric alcohols and their oxidation products will be described and discussed in the following order:

1. *Glycols, Dihydric Alcohols.*
2. *Hydroxyaldehydes, Aldehyde Alcohols.*
3. *Hydroxyketones, Ketone Alcohols.*
4. *Dialdehydes.*
5. *Aldehyde Ketones.*
6. *Diketones.*
7. *Hydroxyacids, Alcohol Monocarboxylic Acids.*
8. *Aldehyde Monocarboxylic Acids.*
9. *Keto-monocarboxylic Acids.*
10. *Dicarboxylic Acids.*

From the very nature of the conditions there are no compounds in any of these series which contain but one carbon atom in the molecule. However, carbonic acid with its exceedingly numerous derivatives will be introduced before the dicarboxylic acids—the *carbonic acid group*.

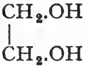
Carbonic acid is the simplest dibasic acid; it is similar, in many respects, to the dicarboxylic acids and a special type for such acids, which, like it, only occur in an anhydride form. Formic acid, the simplest acid, showing, at one and the same time, the character of an aldehyde and a monocarboxylic acid, might, for the very same reason, have been placed before *glyoxylic acid*, at the head of the aldehyde acids. However, it is customary to place formic acid at the head of the fatty acids, because the acid nature in it appears more prominently than does its aldehyde character.

1. DIHYDRIC ALCOHOLS OR GLYCOLS

A. PARAFFIN GLYCOLS

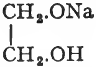
Würtz (1856) discovered glycol, and thus succeeded in filling the gap between the monohydric alcohols and the triacid alcohol, glycerol. He chose the name glycol to indicate the relation of the new body to alcohol on the one hand and glycerol on the other. Glycols are distinguished as α-, β-, γ-, δ-, etc., according as the hydroxyls are attached to adjacent carbon atoms (1,2), or in 1,3-, 1,4-, and 1,5- positions respectively. There are also diprimary, primary-secondary, etc., glycols (consult p. 307). The Geneva names are obtained for the glycols by attaching the final syllable "diol" to the name of the parent hydrocarbon.

Glycols differ from the monohydric alcohols just as the hydroxides of bivalent metals differ from those of univalent metals, or as a dibasic acid from a monobasic acid. As a rule, the reactions leading from the monohydric alcohols and glycols to their corresponding derivatives are very similar. It is only in the case of the two hydroxyl groups of the glycols that they are able to pass successively to completion, and in so doing they give rise first to substances which still show the character of a monohydric alcohol. Take ethylene glycol, for example: it is capable of forming a mono- and dialkali glycollate, corresponding with the alcoholates of the monohydric alcohols, mono- and dialkyl ethers, mono- and dihalogen esters, nitric acid esters and esters of organic acids, *e.g.*:



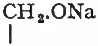
$$\begin{array}{l} CH_2.OH \\ | \\ CH_2.OH \end{array}$$

Glycol.



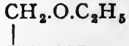
$$\begin{array}{l} CH_2.ONa \\ | \\ CH_2.OH \end{array}$$

Monosodium Glycollate.



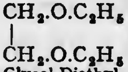
$$\begin{array}{l} CH_2.ONa \\ | \\ CH_2.ONa \end{array}$$

Disodium Glycollate.



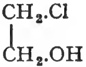
$$\begin{array}{l} CH_2.O.C_2H_5 \\ | \\ CH_2.OH \end{array}$$

Glycol Mono-ethyl Ether.



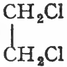
$$\begin{array}{l} CH_2.O.C_2H_5 \\ | \\ CH_2.O.C_2H_5 \end{array}$$

Glycol Diethyl Ether.



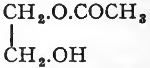
$$\begin{array}{l} CH_2.Cl \\ | \\ CH_2.OH \end{array}$$

Glycol Chlorhydrin.



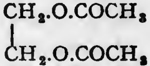
$$\begin{array}{l} CH_2Cl \\ | \\ CH_2Cl \end{array}$$

Ethylene Chloride.



$$\begin{array}{l} CH_2.O.COCH_3 \\ | \\ CH_2.OH \end{array}$$

Glycol Monacetate.

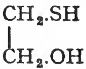


$$\begin{array}{l} CH_2.O.COCH_3 \\ | \\ CH_2.O.COCH_3 \end{array}$$

Glycol Diacetate.

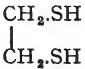
All the mono compounds also exhibit the character of monohydric alcohols; they and the di- compounds, which have been mentioned, can be obtained from the glycols by the same methods as the corresponding transposition products of the monohydric alcohols.

The sulphur- and nitrogen-containing derivatives of the glycols correspond with like derivatives of the monohydric alcohols:



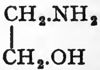
$$\begin{array}{l} CH_2.SH \\ | \\ CH_2.OH \end{array}$$

Monothio-glycol.



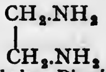
$$\begin{array}{l} CH_2.SH \\ | \\ CH_2.SH \end{array}$$

Dithio-glycol.



$$\begin{array}{l} CH_2.NH_2 \\ | \\ CH_2.OH \end{array}$$

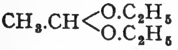
Hydroxyethylamine.



$$\begin{array}{l} CH_2.NH_2 \\ | \\ CH_2.NH_2 \end{array}$$

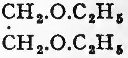
Ethylene Diamine.

The aldehydes have been repeatedly spoken of as the anhydrides of dihydric alcohols, in which the two hydroxyl groups are joined to the *same carbon atom*, and which can only exist under special conditions. Yet, the ethers or acetals, esters and other derivatives of these hypothetical compounds are stable. These bodies are naturally isomeric with the corresponding derivatives of the dihydric alcohols, in which the hydroxyls are attached to *different carbon atoms*. The following, for example, are isomeric:—



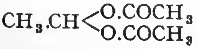
$$CH_3.CH{<}\begin{array}{l} O.C_2H_5 \\ O.C_2H_5 \end{array}$$

Acetal and



$$\begin{array}{l} CH_2.O.C_2H_5 \\ \cdot \\ CH_2.O.C_2H_5 \end{array}$$

Glycol Diethyl Ether

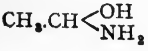


$$CH_3.CH{<}\begin{array}{l} O.COCH_3 \\ O.COCH_3 \end{array}$$

Ethylidene Diacetate and

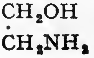
$$\begin{array}{l} CH_2.O.COCH_3 \\ \cdot \\ CH_2.O.COCH_3 \end{array}$$

Glycol Diacetate



$$CH_3.CH{<}\begin{array}{l} OH \\ NH_2 \end{array}$$

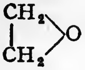
Aldehyde Ammonia and



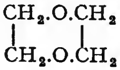
$$\begin{array}{l} CH_2OH \\ \cdot \\ CH_2NH_2 \end{array}$$

Hydroxyethylamine.

The *cyclic derivatives of the glycols* are extremely characteristic. Thus, glycol yields two cyclic ethers:



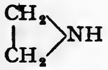
Ethylene Oxide.



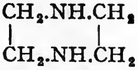
$$\begin{array}{l} CH_2.O.CH_2 \\ | \quad\quad\quad | \\ CH_2.O.CH_2 \end{array}$$

Diethylene Oxide,

and also sulphur- and nitrogen-compounds corresponding with diethylene oxide:

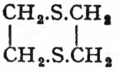


Ethylene Imide.



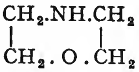
$$\begin{array}{l} CH_2.NH.CH_2 \\ | \quad\quad\quad\quad | \\ CH_2.NH.CH_2 \end{array}$$

Diethylene Imide.



$$\begin{array}{l} CH_2.S.CH_2 \\ | \quad\quad\quad | \\ CH_2.S.CH_2 \end{array}$$

Diethylene Disulphide.



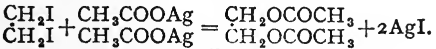
$$\begin{array}{l} CH_2.NH.CH_2 \\ | \quad\quad\quad\quad | \\ CH_2\,.\,O\,.\,CH_2 \end{array}$$

Diethylene Imide Oxide.

Methods of Formation.—The first three methods are concerned with the olefines, and lead, according to the constitution of the latter, to glycols of every description.

The halogen addition products of the olefines—the alkylene halides—may be regarded as the *halogen acid esters* of the glycols. When these are acted on by alkalis, with the purpose of exchanging hydroxyl for their halogen, by loss of halogen acid, they pass first into monohalogen olefines and then into acetylenes. It was *Würtz* who observed that it was only necessary to treat the alkylene halides with acetates in order to reach the acetic esters of the glycols, and then, by saponification with alkalis, to obtain the glycols.

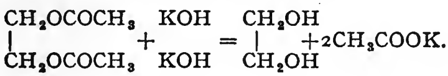
(1) By heating the alkylene halides (p. 94) with silver acetate and glacial acetic acid, or with potassium acetate in alcoholic solution:



$$\begin{array}{l} CH_2I \\ CH_2I \end{array} + \begin{array}{l} CH_3COOAg \\ CH_3COOAg \end{array} = \begin{array}{l} CH_2OCOCH_3 \\ CH_2OCOCH_3 \end{array} + 2AgI.$$

Ethylene Diacetate.

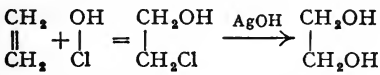
Inasmuch as the alkylenes are prepared from monohydric alcohols by withdrawal of water, and are transformed by the addition of halogens into alkylene halides, the preceding reaction may be regarded as a method of converting monohydric alcohols into dihydric alcohols or glycols. The resulting acetic esters are purified by distillation, and then saponified by KOH or barium hydroxide solution (C. 1899, I. 968):



$$\begin{array}{l} CH_2OCOCH_3 \\ | \\ CH_2OCOCH_3 \end{array} + \begin{array}{l} KOH \\ \\ KOH \end{array} = \begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array} + 2CH_3COOK.$$

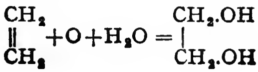
A direct conversion of alkylene halides into glycols may be attained by heating them with water (A. **186**, 293), with water and lead oxide, or sodium and potassium carbonates.

(2) Another procedure consists in shaking the alkylenes, C_nH_{2n}, with aqueous hypochlorous acid, and afterwards decomposing the chlorhydrins formed with moist silver oxide:



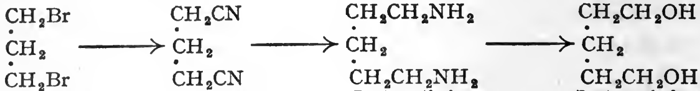
$$\begin{array}{l} CH_2 \\ \| \\ CH_2 \end{array} + \begin{array}{l} OH \\ | \\ Cl \end{array} = \begin{array}{l} CH_2OH \\ | \\ CH_2Cl \end{array} \xrightarrow{AgOH} \begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array}$$

(3) By the oxidation of the olefines (*a*) in alkaline solution (p. 84) (*Wagner*, B. **21**, 1230) with potassium permanganate, or (*b*) with hydrogen peroxide. Thus, ethylene yields *ethylene glycol;* isobutylene, *isobutylene glycol,* $(CH_3)_2.C(OH).CH_2.OH$:



$$\begin{array}{l} CH_2 \\ \| \\ CH_2 \end{array} + O + H_2O = \begin{array}{l} CH_2.OH \\ | \\ CH_2.OH \end{array}$$

(4) By the action of nitrous acid on diamines (p. 163). As they can be obtained from the corresponding nitriles of dibasic acids, and the nitriles themselves from alkylene halides, these reactions not only ally the classes of derivatives mentioned, but they afford a means of building up the glycols :



$$\begin{matrix} CH_2Br \\ \cdot \\ CH_2 \\ \cdot \\ CH_2Br \end{matrix} \longrightarrow \begin{matrix} CH_2CN \\ \cdot \\ CH_2 \\ \cdot \\ CH_2CN \end{matrix} \longrightarrow \begin{matrix} CH_2CH_2NH_2 \\ \cdot \\ CH_2 \\ \cdot \\ CH_2CH_2NH_2 \end{matrix} \longrightarrow \begin{matrix} CH_2CH_2OH \\ \cdot \\ CH_2 \\ \cdot \\ CH_2CH_2OH \end{matrix}$$

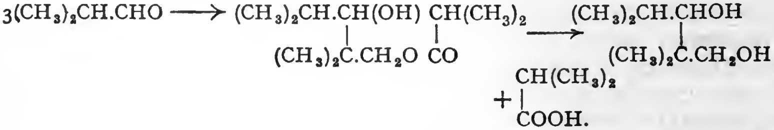
Trimethylene Bromide. Trimethylene Cyanide. Pentamethylene Diamine. Pentamethylene Glycol.

Besides the normal glycols, isomeric glycols are sometimes obtained, as well as olefine alcohols and diolefines (B. **40,** 2589).

(5*a*) By reduction of aldehydes or keto-alcohols, dialdehydes or diketones.

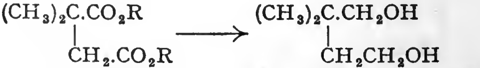
By this means the α-keto-alcohols butyroïn and caproïn (p. 342) yield the stereoisomeric forms of 4,5-octane-diol and 6,7-decanedodiol ; aldol (p. 338) gives $\alpha\gamma$-butylene glycol ; γ-acetobutyl alcohol (p. 342) gives 1,5-hexane-diol, and acetonyl acetone (p. 351) yields 2,5-hexane-diol.

Akin to these reactions is the formation of glycol by the condensation of isobutyl alcohol, alone or when mixed with other aldehydes, by means of alcoholic potassium hydroxide. An *aldol* (p. 338) is first formed, of which the aldehydic group is acted on by excess of butyl aldehyde producing a monobutyrin of the 1,3-glycol (comp. p. 194), which in turn is decomposed by hydrolysis into the glycol and isobutyric acid (M. **17,** 68 ; **19,** 16) :



$$3(CH_3)_2CH.CHO \longrightarrow \begin{array}{l} (CH_3)_2CH.CH(OH)\ CH(CH_3)_2 \\ \qquad\quad | \qquad\qquad | \\ (CH_3)_2C.CH_2O\ CO \end{array} \longrightarrow \begin{array}{l} (CH_3)_2CH.CHOH \\ \qquad\qquad | \\ (CH_3)_2C.CH_2OH \end{array} + \begin{array}{l} CH(CH_3)_2 \\ | \\ COOH. \end{array}$$

(5*b*) By the reduction of dicarboxylic esters or amides by sodium and alcohol (C. 1905, II. 1701).



$$\begin{array}{l} (CH_3)_2C.CO_2R \\ \qquad | \\ \quad CH_2.CO_2R \end{array} \longrightarrow \begin{array}{l} (CH_3)_2C.CH_2OH \\ \qquad | \\ \quad CH_2CH_2OH \end{array}$$

unsym.-Dimethyl Succinic Ester. α-Dimethyl Tetramethylene Glycol.

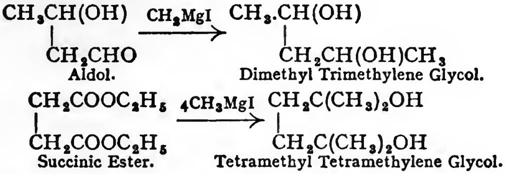
$$\begin{array}{l} CH_2.CH_2.CH_2.CONH_2 \\ | \\ CH_2.CH_2.CH_2.CONH_2 \end{array} \longrightarrow \begin{array}{l} CH_2.CH_2.CH_2CH_2OH \\ | \\ CH_2.CH_2.CH_2CH_2OH. \end{array}$$

Suberic Amide. Octomethylene Glycol.

Lactones, the cyclic esters of γ-, δ-, or ϵ-hydroxy-carboxylic esters, are also reduced to glycols by sodium and alcohol (B. **39,** 2851) ; similarly, β-ethoxyl propionic ester yields the ethyl ether of trimethylene glycol (C. 1905, I. 25).

Nucleus Synthetic Methods

(6*a*) Aldehyde alcohols, diketones, keto-carboxylic esters, dicarboxylic esters, all react with alkyl magnesium halides (p. 185) forming glycols, accompanied by the entry of an alkyl group (B. **35,** 2138; C. 1904, I. 578; 1906, II. 1639; 1907, I. 627):



$$\begin{array}{l}CH_3CH(OH)\\ |\\ CH_2CHO\end{array}\xrightarrow{CH_3MgI}\begin{array}{l}CH_3.CH(OH)\\ |\\ CH_2CH(OH)CH_3\end{array}$$

Aldol. Dimethyl Trimethylene Glycol.

$$\begin{array}{l}CH_2COOC_2H_5\\ |\\ CH_2COOC_2H_5\end{array}\xrightarrow{4CH_3MgI}\begin{array}{l}CH_2C(CH_3)_2OH\\ |\\ CH_2C(CH_3)_2OH\end{array}$$

Succinic Ester. Tetramethyl Tetramethylene Glycol.

By the same reagent alkoxy-ketones and alkoxy-carboxylic esters are converted into monoalkyl ethers of the glycols (C. 1904, I. 504). Similarly, lactones yield primary-tertiary glycols (C. 1907, I. 708).

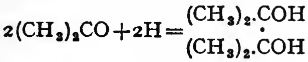
(6*b*) The action of metals, such as sodium or magnesium, on many halogen-hydrin compounds of the ethers, either alone or mixed with halogen methyl alkyl ethers (p. 206), is to build up the ethers of the higher glycols from lower members (C. 1903, I. 455; 1904, I. 1401):

$$\underset{\gamma\text{-Phenoxypropyl Iodide.}}{2C_6H_5O.CH_2CH_2CH_2I}\xrightarrow{Na}C_6H_5O[CH_2]_6OC_6H_5\longrightarrow\underset{\text{Hexamethylene Glycol.}}{HO[CH_2]_6OH}$$

$$\underset{\text{Amyloxypropyl Bromide.}}{C_5H_{11}O[CH_2]_3Br}+BrCH_2OC_5H_{11}\xrightarrow{Mg}C_5H_{11}O[CH_2]_4OC_5H_{11}\longrightarrow\underset{\text{Tetramethylene Glycol.}}{HO[CH_2]_4OH}$$

The monoalkyl ethers of the glycols can be obtained by the similar reaction of chloromethyl alkyl ether on ketones in the presence of magnesium or other metals (C. 1907, I. 681).

(7) *Ditertiary glycols* result, together with secondary alcohols, in the reduction of ketones (p. 230). In this manner *pinacone* or *tetramethyl ethylene glycol* (p. 313) was made from acetone (*Friedel*):



$$2(CH_3)_2CO+2H=\begin{array}{l}(CH_3)_2.COH\\ \quad\quad\;\;\cdot\\ (CH_3)_2.COH\end{array}$$

(8) A few glycols have been obtained in the form of their dialkyl ethers by the electrolysis of alkoxy-carboxylic acids. This is similar to the production of ethane from potassium acetate (p. 73, and C. 1905, I. 1698).

Properties.—The glycols are neutral, thick liquids, holding, as far as their properties are concerned, a place intermediate between the monohydric alcohols and trihydric glycerol. The solubility of a compound in water increases according to the accumulation of OH groups in it, and becomes correspondingly less soluble in alcohol, and especially in ether. There will be also an appreciable rise in the boiling point, whilst the body acquires at the same time a sweet taste, inasmuch as there occurs a gradual transition from the hydrocarbons to the sugars. In accord with this, the glycols have a sweetish taste, are very easily soluble in water, slightly soluble in ether, and boil much higher (about 100°) than the corresponding monohydric alcohols. As the number and dimensions of the alkyl groups grow, the higher homologues become increasingly soluble in ether, and the taste becomes sharper and, in some cases, burning.

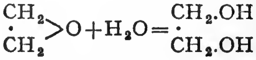
Behaviour.—(1) Towards dehydrating agents: (*a*) The 1,2-glycols, when heated with zinc chloride, P_2O_5, dilute acids or even water at high temperatures, are converted into aldehydes or ketones, *e.g.* $CH_3CH(OH)CH_2OH \longrightarrow CH_3.CH_2.CHO$ and CH_3COCH_3 (see also the transformations of the glycols and changes of the pinacones pp. 216, 313). (*b*) The 1,4- and 1,5-glycols yield cyclic oxides (p. 316). (*c*) The 1,3-glycols form cyclic oxides and also aldehydes and ketones (M. **23**, 60).

(2) Many glycols, especially the primary, when oxidized, pass into the corresponding oxidation products (see Ethylene Glycol); others break down with fracture of the carbon chains.

(3) On the reactions with halogen acids, nitric acid, concentrated sulphuric acid, acid chlorides, and acid anhydrides, see esters of the glycols (p. 319).

I. **Ethylene Glycol**, *Glycol*, [1,2-Ethane diol], $CH_2OH.CH_2OH$, m.p. −11·5°, b.p. 197·5°, $D_0 = 1·125$, is miscible with water and alcohol. Ether dissolves but small quantities of it.

It may be obtained from ethylene through ethylene bromide, ethylene chlorhydrin (general method of formation, p. 309) or by direct oxidation; and also from ethylene oxide by the absorption of water:

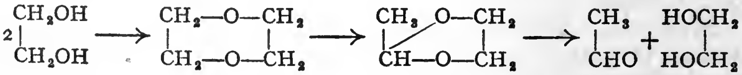


$$\begin{matrix}CH_2\\ \cdot\\ CH_2\end{matrix}\!\!>O + H_2O = \begin{matrix}CH_2.OH\\ \cdot\\ CH_2.OH\end{matrix}$$

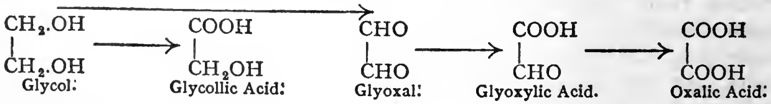
Preparation.—A mixture of ethylene bromide, potassium carbonate and water is boiled under a reflex condenser, until all the bromide is dissolved (A. **192**, 240, 250). Or the ethylene bromide may be converted by heating with anhydrous potassium acetate into glycol diacetate, which yields glycol when hydrolyzed with alkali hydroxide (B. **29**, R. 287; C. 8991, I. 968).

Behaviour.—(1) On heating ethylene glycol with zinc chloride to 250° water is eliminated and acetaldehyde and crotonaldehyde are formed; at 210° with water, only acetaldehyde results.

When ethylene glycol is distilled with 4 per cent. concentrated sulphuric acid, not only acetaldehyde and ethylidene ethylene ether (p. 317) are formed, but also *Diethylene Oxide.* Further treatment with sulphuric acid or zinc chloride results similarly in the production of acetaldehyde:



(2) Nitric acid oxidizes glycol to glycollic acid and glyoxal, glyoxylic acid and oxalic acid. The first oxidation product, glycol aldehyde (*q.v.*), is further oxidized too rapidly to be identified:



(3) When glycol is heated with potassium hydroxide to 250°, it is oxidized to oxalic acid with evolution of hydrogen.

(4) Heated to 160° with concentrated hydrochloric acid, *glycol chlorhydrin* results, which at 200° is converted into *ethylene chloride.*

(5) The latter is also produced when PCl_5 acts on glycol.

(6) A mixture of nitric and sulphuric acids changes glycol into *glycol dinitrate*.

(7) Concentrated sulphuric acid and glycol yield *glycol sulphate*.

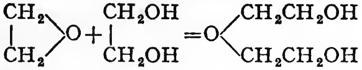
(8) The acid chlorides or acid anhydrides produce mono- and di-esters of glycol.

Glycollates :

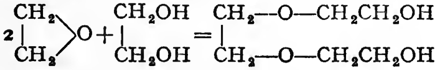
Metallic sodium dissolves in glycol, forming *sodium glycollate*, $C_2H_4<^{OH}_{ONa}$, and (at 170°) *disodium glycollate*, $C_2H_4(ONa)_2$. Both are white, crystalline substances, regenerating glycol with water. The alkylogens convert them into the corresponding ethers.

Polyethylene Glycols :

Ethylene oxide absorbs water and becomes glycol. The latter and ethylene oxide unite at 100° in varying proportions, thus yielding the polyethylene glycols:



Diethylene Glycol, b.p. 250°.



Triethylene Glycol, b.p. 287°.

etc.

The polyglycols are thick liquids, with high boiling points. They behave like the glycols. *Ether-acids* may be obtained from them by oxidation with dilute nitric acid ; thus *diglycollic acid* (*q.v.*) is formed from diethylene alcohol.

There are two series of *homologues* of ethylene glycol ; the one resulting from alkyl substitution, and the other, including the 1,3-, 1,4-,1,5-glycols, etc., produced by the insertion of an alkyl group between the carbinol groups.

II. Homologous 1,2-glycols.

α-Propylene Glycol, Methyl Ethylene Glycol [Propane diol-1,2], $CH_3.CH(OH).CH_2.OH$, b.p. 188°, $D_0=1{\cdot}015$, is obtained from propylene bromide or chloride. It is most readily prepared by distilling glycerol with sodium hydroxide (B. **13**, 1805). Platinum black oxidizes it to *ordinary lactic acid*. Only acetic acid is formed when chromic acid is the oxidizing agent. Concentrated hydriodic acid changes it to isopropyl alcohol and its iodide. Heated with water at about 190° it yields propylaldehyde and acetone. It contains an asymmetric carbon atom, and when exposed to the action of the ferment *Bacterium termo*, becomes optically active (B. **14**, 843).

α-Butylene Glycol, Ethyl Ethylene Glycol, $C_2H_5CH(OH).CH_2OH$, b.p. 192°.

βγ-Butylene Glycol, sym.-*Dimethyl Ethylene Glycol*, $CH_3CH(OH).CH(OH).CH_3$, b.p. 184°.

Isobutylene Glycol, unsym.-*Dimethyl Ethylene Glycol*, $(CH_3)_2C(OH).CH_2(OH)$, b.p. 177°.

Are obtained from the corresponding butylene bromides.

α-Isoamylene Glycol, Isopropyl Ethylene Glycol, $(CH_3)_2CH.CH(OH).CH_2OH$, b.p. 206°.

β-Isoamylene Glycol, Trimethyl Ethylene Glycol, $(CH_3)_2C(OH).CH(OH)CH_3$, b.p. 177°.

β-Amylene Glycol, sym.-*Ethyl Methyl Ethylene Glycol*, $C_2H_5CH(OH)CH(OH).CH_3$, b.p. 187°.

Are obtained from the corresponding amylene dibromides.

Pinacone, *Tetramethyl Ethylene Glycol*, $(CH_3)_2.C(OH).C(OH).(CH_3)_2+6H_2O$, m.p. 42°, *anhydrous*, m.p. 38°, b.p. 171–172°, is formed, together with isopropyl alcohol, when sodium or magnesium and mercuric chloride (C. 1906, II. 148) act on acetone; or by electrolysis (B. **27**, 454; C. 1900, II. 794) (see method of formation, No. 8, p. 311). Further, by the action of $IMgCH_3$ on diacetyl or oxalic ester (mode of formation, No. 6a). It crystallizes from its aqueous solution in quadratic plates (hence the name, from πίναξ, plate), and gradually effloresces on exposure.

In common with other ketones (p. 216), dilute sulphuric or hydrochloric acids cause it to lose water and undergo intramolecular change, forming *pinacoline* or tert.-butyl methyl ketone (p. 224). An isomer of this substance exists—*tetramethyl ethylene oxide* (p. 318), which very readily absorbs water forming pinacone.

Similarly to pinacone, a whole series of *tetra-alkylated ethylene glycols* can be prepared by reduction of aliphatic ketones, known collectively as *Pinacones*, which behave towards dilute sulphuric and hydrochloric acids as pinacone itself does. Comp. *Methyl Isopropyl Pinacone*, C. 1903, II. 23.

sym.-**Dipropyl Ethylene Glycol** [Octane diol-4,5], $C_3H_7CH(OH).CH(OH)C_3H_7$, occurs in two modifications; α-form, liquid, b.p.$_{10}$ 115–120°, β-form, m.p. 125°, and is prepared by reduction of butyroïn (p. 342) by sodium and alcohol.

sym.-**Dipentyl-ethylene Glycol** [Dodecane diol-6,7], α-form, m.p. 54°, b.p.$_{10}$ 155–160°; β-form, m.p. 136°, is produced when capronoïn is reduced by sodium and alcohol (C. 1906, II. 1114).

III. 1,3-Glycols.

Trimethylene Glycol [Propane diol-1,3], $CH_2OH.CH_2CH_2OH$, b.p. 216°, D.$_0$= 1·065, is obtained from trimethylene bromide (B. **16**, 393); or by the fermentation of glycerol by Schizomycetes, together with *n*-butyl alcohol (B. **20**, R. 706). It is isomeric with α-propylene glycol. Moderate oxidizing agents produce *β-Hydroxypropionic Acid* or *Hydracrylic Acid*; sulphuric acid changes it into propionaldehyde and acetone (C. 1904, I. 1401).

β-Butylene Glycol, β-Methyl Trimethylene Glycol [Butane diol-1,3] $CH_3CH(OH)$-CH_2OH, b.p. 207°, is obtained by the reduction of aldol (p. 338); 50 per cent. sulphuric acid converts it into butyl aldehyde and methyl ethyl ketone (comp. p. 312, and C. 1904, I. 1400).

γ-Isoamylene Glycol, αα-Dimethyl Trimethylene Glycol, $(CH_3)_2C(OH).CH_2CH_2$-OH, b.p. 203°, is obtained from the bromide (B. **29**, R. 92).

sym.-*Dimethyl Trimethylene Glycol* [Pentane diol-2,4], $CH_3CH(OH)CH_2CH$-$(OH)CH_3$, b.p. 199°, is prepared by reduction of hydracetyl acetone (p. 342); and by the action of magnesium methyl iodide on aldol (C. 1904, I. 1327; B. **37**, 4730).

ααγ-Trimethyl Trimethylene Glycol, 2,4-Isohexylene Glycol, $(CH_3)_2C(OH)CH_2$-$CH_2CH(OH)CH_3$, b.p. 194°, is obtained by reduction of diacetone alcohol (p. 342).

sym.-*Tetramethyl Trimethylene Glycol*, $(CH_3)_2C(OH).CH_2.C(OH)(CH_3)_2$, b.p.$_{13}$ 98°, results from the action of CH_3MgI on diacetone alcohol (C. 1902, I. 455; B. **37**, 4731).

A series of higher homologues of the 1,3-glycols is obtained from the condensation of isobutyl aldehyde with other aldehydes, such as the isobutyl aldols, by means of alcoholic potassium hydroxide (method of formation No. 5*a*, p. 310).

ββ-Dimethyl Trimethylene Glycol, *Pentaglycol*, $(CH_3)_2C(CH_2OH)_2$, m.p. 129°, b.p. 206°. Heated with H_2SO_4 it forms isovaleric aldehyde, isopropylmethyl ketone and a cyclic oxide (C. 1900, II. 36). *αββ-Trimethyl Trimethylene Glycol*, $CH_2(OH)C(CH_3)_2CH(OH)CH_3$, b.p. 207°, and *αββ-Ethyl Dimethyl Trimethylene Glycol*, m.p. 81°, are obtained from isobutyl aldehyde, and acetaldehyde and propionaldehyde, respectively. *αββ-Isopropyl Dimethyl Trimethylene Glycol*, $CH_2(OH)C(CH_3)_2CH(OH)C_3H_7$, m.p. 51°, b.p. 223°, is prepared from isobutyl aldehyde alone. This substance on oxidation yields first a hydroxy-acid and then diisopropyl ketone.

sym.-*Tetramethyl β-Ethyl Trimethylene Glycol*, $(CH_3)_2C(OH)CH(C_2H_5)C(OH)$-$(CH_3)_2$, b.p.$_{11}$ 128°, is obtained from ethyl acetoacetic ester and CH_3MgI (mode of formation 6*a*, p. 310) (C. 1902, I. 1197).

IV. 1,4-Glycols.

Tetramethylene Glycol, [Butane diol-1,4], $HO.CH_2.CH_2.CH_2CH_2OH$, b.p. 202–203°, D=1·011, is prepared from tetramethylene dinitramine and sulphuric acid (B. **23**, R. 506); also, by reduction of succinic dialdehyde (p. 347), by aluminium amalgam. It possesses an unpleasant odour of leeks (B. **35**, 1187).

The *Diamyl Ether* results from the electrolysis of the potassium salt of β-amyloxypropionic acid (C. 1901, I. 613 ; 1905, I. 1698).

α-Methyl Tetramethylene Glycol, (Pentane diol-1,4), $CH_3.CH(OH)CH_2CH_2CH_2OH$, b.p.$_{18}$ 123–126°, with partial decomposition into γ-pentylene oxide and water. It is obtained from acetopropyl alcohol (C. 1903, II. 531) and from γ-valerolactone by reduction (B. **39,** 2851).

α-Dimethyl Tetramethylene Glycol, 1,4-*Isohexylene Glycol,* $(CH_3)_2C(OH)CH_2CH_2CH_2OH$, b.p. 222°, results from the action of CH_3MgI on butyrolactone (C. 1907, I. 708).

β-Dimethyl Tetramethylene Glycol, $CH_2(OH)C(CH_3)_2CH_2CH_2OH$, b.p.$_{10}$ 123°, is produced from unsym.-dimethyl succinic ester by reduction with sodium and alcohol (1905, II. 178).

αδ-Dimethyl Tetramethylene Glycol, 2,5-*Hexylene Glycol,* [Hexane diol-2,5] $CH_3CH(OH)CH_2CH_2CH(OH)CH_3$, b.p. 217°, is easily obtained by the reduction of acetonyl acetone by sodium amalgam (B. **35,** 1335).

V. 1,5-Glycols.

Pentamethylene Glycol, [Pentane diol-1,5], $HOCH_2.CH_2.CH_2CH_2CH_2OH$, b.p. 239°, $D_{18}=0·994$, is obtained from pentamethylene diamine (mode of formation 4, p. 310) (B. **40,** 2559). *Diamyl Ether* is prepared from δ-amyloxybutyl bromide, magnesium and bromomethyl amyl ether (mode of formation 6b., p. 311) (C. 1904, II. 587).

α-Methyl Pentamethylene Glycol, [Hexane diol-1,5], $CH_3CH(OH)[CH_2]_3CH_2OH$, b.p.$_{710}$ 235°, is produced from acetobutyl alcohol (p. 342).

VI. 1,6-, 1,7-, 1,8-Glycols, etc.

The melting points of these polymethylene glycols appear to follow the same rule as those of the normal paraffin mono- and di-carboxylic acids and other homologous series (p. 48), namely, that those of members possessing an odd number of atoms lie lower than those of the neighbouring even-numbered members (C. 1904, II. 1698).

Hexamethylene Glycol, [Hexane diol-1,6], $HO[CH_2]_6OH$, m.p. 42°, b.p. 250°, is prepared from hexamethylene dibromide or diacetate ; and from adipic ester by reduction. *Dialkyl Ether* is obtained from γ-alkoxypropyl halides by the action of sodium (methods of formation 6*b* and 8 (p. 311); and from γ-amyloxybutyric acid by electrolysis (B. **27,** R. 735 ; C. 1905, I. 1698 ; II. 1701).

Heptamethylene Glycol, *Diethyl Ether,* $C_2H_5O.[CH_2]_7OC_2H_5$, b.p. 225°, results from the interaction of 6-ethoxyhexyl iodide, magnesium and iodomethyl ethyl ether (mode of formation 6b, p. 311) (C. 1906, I. 443).

Octomethylene Glycol, [Octane diol-1,8], $HO[CH_2]_8OH$, m.p. 60°, b.p.$_0$ 162°.

Enneamethylene Glycol, [Nonane diol-1,9], $HO[CH_2]_9OH$, m.p. 45°, b.p.$_{15}$ 177°.

Decamethylene Glycol, [Decane diol-1,10], $HO[CH_2]_{10}OH$, m.p. 70°, b.p.$_{15}$ 179°. These glycols are obtained from dicarboxylic esters or amides by reduction (mode of formation 5*b*, p. 310) (C. 1904, I. 1399 ; 1905, II. 1701).

B. UNSATURATED GLYCOLS, OLEFINE GLYCOLS, ACETYLENE GLYCOLS

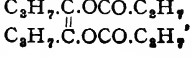
Unsaturated dihydric alcohols have been but slightly investigated. The simplest representatives possible theoretically are not known, and probably are not capable of existing.

See p. 318, upon the view of furfurane as an oxide of an unknown, unsaturated glycol. Also consult acetonyl acetone (p. 351).

iso-*Dipropionyl,* iso-*dibutyryl,* iso-*diisobutyryl,* and iso-*diisovaleryl* are **olefine glycol derivatives.** They resulted from the action of metallic sodium on an ethereal solution of propionyl chloride, butyryl chloride, and isobutyryl chloride, and iso-valeryl chloride. They are esters of alkyl acetylene glycols (*Klinger* and *Schmitz,* B. **24,** 1271 ; B. **28,** R. 1000 ; J. pr. Ch., [2], **63,** 364).

Diethyl Acetylene Glycol Dipropionate, Dipropionyl,

$\begin{array}{l} C_2H_5.C.OCOC_2H_5 \\ \quad\quad\;\, \ddot{} \\ C_2H_5.C.OCOC_2H_5 \end{array}$, b.p.$_{10}$ 108°. *Di-n-propyl Acetylene Glycol Dibutyrate, Dibutyryl,*



$\begin{array}{l} C_3H_7.C.OCO.C_2H_7 \\ \quad\quad\;\, \| \\ C_3H_7.C.OCO.C_3H_7 \end{array}$, b.p.$_{12}$ 119–130°. *Diisobutyl Acetylene Glycol Diisovalerate, Diisovaleryl,* $\begin{array}{l}(CH_3)_2.CH.CH_2.C—OCOC_4H_9\\ (CH_3)_2.CH.CH_2.\ddot{C}—O.COC_4H_9\end{array}$, b.p.$_{12}$ 145–155°. Butyroïn and isovaleroïn, the corresponding α-ketone alcohols (*q.v.*), are produced, and not the alkyl acetylene glycols, when these three compounds are saponified. The *diacetate*, $CH_3C(OCOCH_3):C(OCOCH_3)_3CH_3$, is produced from the di-sodium salt of acetoïn (p. 341) and acetyl chloride.

Hexa-di-ine diol, $CH_2(OH)C\vdots C—C\vdots C.CH_2.OH$, m.p. 111°, is a **diacetylene glycol.** It is formed by the oxidation of the precipitate from propargyl alcohol and ammoniacal cupric chloride with potassium ferricyanide (C. 1897, **1**, 281; II. 183).

GLYCOL DERIVATIVES

I. ALCOHOL ETHERS OF THE GLYCOLS

A. The **alcohol ethers** of the glycols are prepared (1) from the metallic glycolates and alkyl iodide:

$$\begin{array}{l}CH_2ONa\\ |\\ CH_2OH\end{array} + C_2H_5I = NaI + \begin{array}{l}CH_2OC_2H_5\\ |\\ CH_2OH\end{array}$$ *Glycol Monoethyl Ether*, b.p. 127° (B. **35**, 3299).

$$\begin{array}{l}CH_2ONa\\ |\\ CH_2ONa\end{array} + \begin{array}{l}C_2H_5I\\ \\ C_2H_5I\end{array} = 2NaI + \begin{array}{l}CH_2OC_2H_5\\ |\\ CH_2OC_2H_5\end{array}$$ *Glycol Diethyl Ether*, b.p. 123°.

(2) The monoalkyl ethers of ethylene glycol result from the combination of *ethylene oxide* and alcohol.

(3) Dialkyl ethers can be obtained synthetically by means of the methods of formation 6*b* and 8 (p. 311):

(*a*) From halogen-substituted ethers $RO[CH_2]_nX$ and Na or Mg;
(*b*) From ketones with chloromethyl alkyl ethers and magnesium;
(*c*) From alkoxy ketones and alkoxycarboxylic esters with magnesium alkyl halides.
(*d*) From alkoxy fatty acid salts by electrolysis. Hydriodic acid decomposes the neutral ethers into iodoalkyls and glycols (B. **26**, R. 719), which are converted into alkylene iodides by excess of HI.

Hydrobromic acid in the cold converts glycol dialkyl ether into the bromohydrins of the mono-alkyl ether, $RO[CH_2]_nBr$ (C. 1904, I. 1400).

The mono-alkyl ethers of tertiary- primary 1,2-glycols are changed into aldehydes by the action of anhydrous formic or oxalic acid (comp. p. 192).

The polyethylene alcohols are most closely related to the alcohol ethers. They have been already considered after ethylene glycol (p. 312). Diethylene glycol bears the same relation to glycol as ethyl ether to ethyl alcohol:

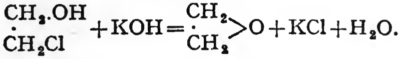
$$O\left<\begin{array}{l}CH_2.CH_2.OH\\ CH_2.CH_2.OH\end{array}\right.,$$ **Diethylene Glycol** (First Ether of Glycol). $$O\left<\begin{array}{l}CH_2.CH_3\\ CH_2.CH_3\end{array}\right.,$$ *Ethyl Ether*.

B. Cyclic Ethers of the Glycols, Alkylen Oxides.

Diethylene Oxide, $O\left<\begin{array}{l}CH_2.CH_2\\ CH_2.CH_2\end{array}\right>O$, m.p. 9°, b.p. 102°, is the second ether of glycol (see above, Diethylene Glycol). It is obtained from the red, crystalline *bromine addition* product of *ethylene oxide*, $(C_2H_4O)_2Br_2$, m.p. 65°, b.p. 95°, when it is treated with mercuric oxide. It is also prepared by heating glycol with concentrated sulphuric acid (p. 312). It unites with bromine, forming the above-mentioned *dibromide*; with iodine, to a *diiodide*, m.p. 85°; and with sulphuric acid it forms a *sulphate*, m.p. 101°. Thus, it forms double compounds or *oxonium* salts similar to those of the simple ethers (p. 126) (C. 1907, I. 1103). It is decomposed into acetaldehyde and glycol when heated with sulphuric acid (p. 312).

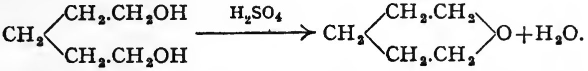
Ethylene Methylene Ether, Glycol Methylene Acetal, $\begin{array}{l}CH_2.O\\ \vdots\\ CH_2.O\end{array}\!\!>CH_2$, b.p. 78°, is obtained from trioxymethylene, ethylene glycol and ferric chloride (B. **28**, R. 109), or syrupy phosphoric acid (C. 1899, I. 919). Also from glycol, formaldehyde and hydrochloric acid (C. 1900, II. 1261). *Ethylene Ethylidene Ether*, $\begin{array}{l}CH_2.O\\CH_2.O\end{array}\!>CH.CH_3$, b.p. 82·5°, results from the union of ethylene oxide and acetaldehyde (comp. p. 312). Diethylene oxide is a cyclic double ether. For the preparation of this class of substance the 1,3-glycols seem also to be suitable (M. **23**, 67). Simple cyclic ethers or glycol oxides are also known; and a *third* ether, *Ethylene Oxide*, $\begin{array}{l}CH_2\\CH_2\end{array}\!>O$ (*Würtz*), is also derived from glycol.

The simple cyclic ethers of the glycols, the alkylene oxides, are readily produced in various ways, depending upon whether the two OH-groups are attached to adjacent carbon atoms or not. Alkylene oxides, in which the O-atoms are in union with adjacent carbon atoms, are termed the α-alkylene oxides, whilst the others are the β-, γ-, δ-alkylene oxides. (1) Ethylene oxide itself and the ethylene oxides, as well as the β-alkylene oxides (trimethylene oxide), are prepared by the action of potassium hydroxide on the *chlor-* or *brom-hydrins*, the monohaloid esters of the respective glycols:



$$\begin{array}{l}CH_2.OH\\ \dot{C}H_2Cl\end{array} + KOH = \begin{array}{l}CH_2\\ \dot{C}H_2\end{array}\!>O + KCl + H_2O.$$

(2) The γ- and δ-alkylene oxides (*γ-pentylene oxide, pentamethylene oxide*), are formed when the glycols are heated with sulphuric acid (B. **18**, 3285; **19**, 2843; M. **23**, 67):

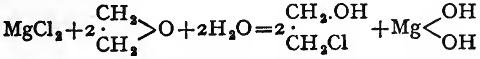


$$CH_2\!<\!\begin{array}{l}CH_2.CH_2OH\\CH_2.CH_2OH\end{array} \xrightarrow{H_2SO_4} CH_2\!<\!\begin{array}{l}CH_2.CH_2\\CH_2.CH_2\end{array}\!>O + H_2O.$$

The α-glycols, under like treatment, lose water and yield either unsaturated alcohols, aldehydes, or pinacolines, depending upon their constitution (pp. 192, 216, 312).

The ethylene oxide ring is easily ruptured, hence ethylene oxide enters into addition reactions quite as freely as its isomer acetaldehyde. The rings of tetra- and pentamethylene oxides, however, are far more stable. These can only be broken up by the halogen acids.

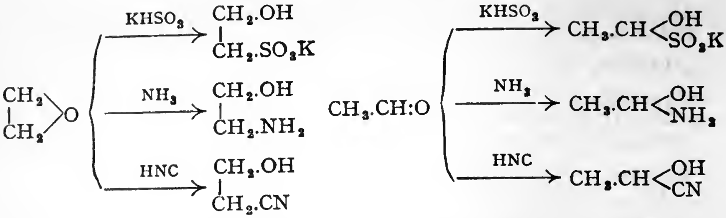
Ethylene Oxide, $\begin{array}{l}CH_2\\ \dot{C}H_2\end{array}\!>O$, b.p. 12·5°, $D._0=0·898$, isomeric with acetaldehyde, $CH_3.CHO$, is a pleasantly smelling, ethereal, mobile liquid, with a neutral reaction, yet able gradually to precipitate metallic hydroxides from many metallic salts.



$$MgCl_2 + 2\begin{array}{l}CH_2\\ \dot{C}H_2\end{array}\!>O + 2H_2O = 2\begin{array}{l}CH_2.OH\\ \dot{C}H_2Cl\end{array} + Mg\!<\!\begin{array}{l}OH\\OH\end{array}$$

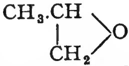
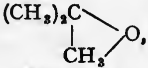
Ethylene oxide is characterized by its additive power. (1) It combines with water and slowly yields *glycol*. (2) Nascent hydrogen converts it into ethyl alcohol. (3) The halogen acids unite with it to form halogenhydrins, the monohaloid esters of the glycols; hydrofluoric acid is, however, an exception (C. 1903, I. 11). (4, *a*) With alcohol it yields glycol monoethyl ether; (*b*) with glycol it forms diethylene glycol; (*c*) and with the latter it combines to triethylene glycol. (5) It forms ethylene alkylidene ethers (p. 316) with aldehydes. (6) Acetic acid and ethylene oxide form glycol monacetate, and (7) with acetic anhydride the product is glycol diacetate. (8) Sodium bisulphite changes it to sodium isethionate. (9) Ammonia changes ethylene oxide to hydroxyethylamine. (10) With hydrocyanic acid it forms the nitrile of *ethylene lactic acid* or *hydracrylic acid*, from which hydrochloric acid produces the ethylene lactic acid itself. (11) Ethylene oxide unites with sodium malonic ester (see Hydroxethyl Malonic Ester). Potassium hydroxide polymerizes ethylene oxide at 50–60° (B. 28, R. 293).

For comparison, the following additive reactions of ethylene oxide and aldehyde are arranged side by side:

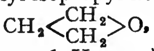


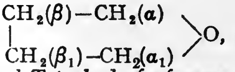
Ethylene oxide and magnesium alkyl halides form addition compounds, which are converted by heat into primary alcoholates, RCH_2CH_2OMgX (pp. 107, 185).

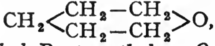
Heated with a little potassium hydroxide at 50–60°, ethylene oxide polymerizes (B. **28**, R. 295).

α-Propylene Oxide,  b.p. 35°. *Isobutylene Oxide,*  b.p. 51–52°. sym.-*Dimethyl Ethylene Oxide,* b.p. 56–57°. sym.-*Methyl Ethyl Ethylene Oxide,* b.p. 80°. *Isopropyl Ethylene Oxide,* b.p. 82°. *Trimethyl Ethylene Oxide,* b.p. 75–76°. *Tetramethyl Ethylene Oxide,* b.p. 95–96°, is produced from tetramethyl ethylene bromide by PbO and water (C. 1902, I. 628). It unites with water to form pinacone with considerable evolution of heat (p. 313).

Heated to 200–260° with Al_2O_3 or other contact substances, ethylene oxide, propylene oxide and isobutylene oxide are transformed into the isomeric aldehydes, acetaldehyde, propionaldehyde, isobutyl aldehyde, whilst trimethyl ethylene oxide gives methyl isopropyl ketone (B. **36**, 2016).

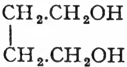
Trimethylene Oxide,  $CH_2<^{CH_2}_{CH_2}>O$, b.p. 50°; preparation, see p. 317; *homologues* (M. **23**, 67; C. 1906, II. 1179).

Tetramethylene Oxide, *Tetrahydrofurfurane,*  b.p. 57° (B. **25**, R. 912). 2,5-*Hexylene Oxide, αα₁-Dimethyl Tetrahydrofurfurane,* b.p. 93° (B. **35**, 1336). *αα-Dimethyl Tetramethylene Oxide,* b.p. 98° (C. 1907, I. 708), *Diisocrotonyl Oxide, αα₁-Tetramethyl Tetrahydrofurfurane,* b.p. 113°. *Diisoamylene Oxide, αα₁-Dimethyl-αα-Diethyl Tetrahydrofurfurane,* b.p. 160° (C. 1899, I. 774, 775). *γ-Pentylene Oxide, α-Methyl Tetrahydrofurfurane,* b.p. 77° (p. 314) (B. **22**, 2571).

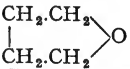
Pentamethylene Oxide,  $CH_2<^{CH_2-CH_2}_{CH_2-CH_2}>O$, b.p. 82° (B. **27**, R. 197).

δ-Hexylene Oxide, α-Methyl Pentamethylene Oxide, b.p. 104°, does not unite with ammonia (B. **18**, 3283). The higher polymethylene glycols are converted into their oxides with difficulty. *Decamethylene Oxide,* b.p. 181°, has, however, been prepared, by distilling the chlorohydrin of decamethylene glycol over sodium hydroxide (C. 1906, II. 596).

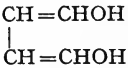
Addendum.—**Furfurane** corresponds with tetramethylene oxide. It may be considered as the cyclic ether of an unknown, unsaturated glycol. It is probable that this glycol could not exist; it would be more likely to become rearranged into succinic dialdehyde, and this in turn to γ-butyrolactone (*q.v.*):



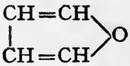
Tetramethylene Glycol.



Tetramethylene Oxide.



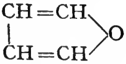
Unknown.



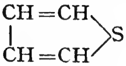
Furfurane.

By the substitution of sulphur and again of the NH-group for oxygen in furfurane the products are thiofurfurane, which, from its remarkable resemblance to benzene, has been called **Thiophene,** and **Pyrrol.**

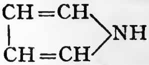
Notwithstanding that the manner of union in the rings of these heterocyclic compounds is not definitely known, it is possible to refer many bodies to them:



Furfurane.



Thiophene.



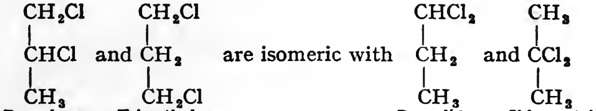
Pyrrole.

All of them contain rings, and they will be discussed later in conjunction with related classes of heterocyclic derivatives.

2. ESTERS OF THE DIHYDRIC ALCOHOLS OR GLYCOLS

A. Esters of Inorganic Acids.

(*a*) **Halogen Esters of the Glycols.**—The glycols and monobasic acids yield neutral and basic esters. The dihalogen substitution products of the paraffins are the neutral or secondary halogen esters of the glycols. The halogen atoms in them are attached to different carbon atoms. They are isomeric with the *aldehyde halides* (p. 206) and the *ketone halides* (p. 225), having an equally large carbon content:

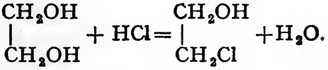


$$\begin{array}{c}CH_2Cl\\|\\CHCl\\|\\CH_3\end{array}\text{ and }\begin{array}{c}CH_2Cl\\|\\CH_2\\|\\CH_2Cl\end{array}\quad\text{are isomeric with}\quad\begin{array}{c}CHCl_2\\|\\CH_2\\|\\CH_3\end{array}\text{ and }\begin{array}{c}CH_3\\|\\CCl_2\\|\\CH_3\end{array}$$

Propylene Chloride. Trimethylene Chloride. Propylidene Chloride (p. 206). Chloracetol (p. 225).

The basic or primary haloid esters of the glycols are the **halohydrins.** These are obtained:

(1) When the glycols are treated with hydrochloric and hydrobromic acids:

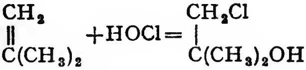


$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}+HCl=\begin{array}{c}CH_2OH\\|\\CH_2Cl\end{array}+H_2O.$$

When heated with HI, a more far-reaching reaction occurs. Ethyl iodide (p. 136) is obtained from ethylene glycol.

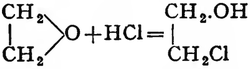
The result of the action of HBr on neutral glycol ethers in the cold is the production of the *ether* of the bromhydrin. Like the ether of the chlorhydrin, it can also be obtained from the benzoyl derivative of the alkoxy-alkylamines by PCl_5 or PBr_5, with the loss of benzonitrile (comp. p. 320) (B. **38**, 960).

(2) They can be obtained, too, by the direct addition of hypochlorous acid (see Inorg. Chem.) to the olefines, whereby the OH group becomes attached to the carbon atom poorest in hydrogen (J. pr. Ch. [2] **64**, 102, 387; comp. C. 1902, I. 1316):



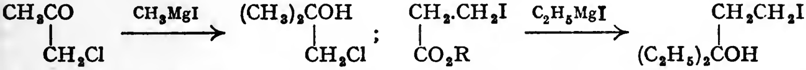
$$\begin{array}{c}CH_2\\\|\\C(CH_3)_2\end{array}+HOCl=\begin{array}{c}CH_2Cl\\|\\C(CH_3)_2OH\end{array}$$

(3) By the action of halogen acids on ethylene oxide and its homologues:



$$\begin{array}{c}CH_2\\|\\CH_2\end{array}\!\!>O+HCl=\begin{array}{c}CH_2.OH\\|\\CH_2Cl\end{array}$$

(4) Synthetically, it can be prepared from haloid ketones or haloid carboxylic esters and alkyl magnesium halides (B. **39**, 225, 3678; C. 1906, I. 1584, II. 1179):



$$\begin{array}{c}CH_3CO\\|\\CH_2Cl\end{array}\xrightarrow{CH_3MgI}\begin{array}{c}(CH_3)_2COH\\|\\CH_2Cl\end{array};\quad\begin{array}{c}CH_2.CH_2I\\|\\CO_2R\end{array}\xrightarrow{C_2H_5MgI}\begin{array}{c}CH_2CH_2I\\|\\(C_2H_5)_2COH\end{array}$$

Similarly, *a-Chloro-β-ethoxybutane,* $ClCH_2CH(C_2H_5O)C_2H_5$ is prepared from *aβ*-dichlorethyl ether and zinc ethyl (B. **28**, 3111).

Glycol Chlorhydrin, Ethylene Chlorhydrin, $CH_2Cl.CH_2OH$, b.p. 128°. *Glycol Bromhydrin,* b.p. 150°, results also from glycol bromacetin (p. 324) by boiling with methyl alcohol. Similarly *Glycol Iodohydrin,* b.p.$_{16}$ 78°, is obtained from iodoacetin (C. 1901, I. 1356). The iodohydrin is converted completely into acetaldehyde when heated with lead hydroxide (C. 1900, II. 31). *Trimethylene Glycol Chlorhydrin, γ-Chloro-*n*-propyl Alcohol,* $CH_2Cl.CH_2CH_2OH$, b.p. 160°, is obtained from trimethylene glycol by HCl. *α-Propylene Glycol α-Chlorhydrin*, $CH_3CH(OH)$-CH_2Cl, b.p. 127°, is prepared from alkyl chloride by dilute sulphuric acid; also by the addition of HClO to propylene, *α-Propylene Glycol β-Chlorhydrin*, $CH_3CHCl.CH_2OH$, b.p. 134° (C. 1903, II. 486). *Isobutylene Glycol α-Chlorhydrin*, $(OH)C(CH_3)_2CH_2Cl$, b.p. 129°, is obtained from chloracetone or monochloracetic acid by $Mg(CH_3)I$; also from isobutylene and HClO (C. 1902, I. 1093). Isobutylene oxide and HCl gives a mixture of this chlorhydrin and *Isobutylene Glycol β-Chlorhydrin* $(CH_3)_2CCl.CH_2OH$, which easily passes into isobutyl aldehyde (B. **39**, 2789, 3678).

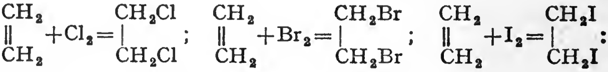
The primary haloid esters can also be considered as substitution products of the monohydric alcohols. Glycol chlorhydrin would be chlorethyl alcohol. (1) Nascent hydrogen converts them into primary alcohols. (2) Oxidizing agents convert them into halogen fatty acids, *e.g.*, glycol chlorhydrin yields *monochloracetic acid;* trimethylene glycol chlorhydrin yields *β-chloropropionic acid.* (3) They change to alkylene oxides, and partially also into aldehydes, under the influence of alkalis. (4) Basic esters of the glycols are produced when they combine with salts of organic acids; *e.g.*, glycol chlorhydrin and potassium acetate yield *glycol mono-acetate*, $CH_3COO.CH_2.CH_2OH$. (5) Potassium cyanide changes them to nitriles of the hydroxyacids.

The *Ethers* of the glycol brom- and iodohydrin can be employed in the building up of the neutral dialkyl ethers of the higher glycols (comp. p. 310).

In close relation to the halohydrins stand certain substances produced by the action of mercury salts on ethylene (p. 82), such as *Mercury Ethanol Iodide*, $HOCH_2.CH_2HgI$, and *Mercury Ether Iodide*, $O(CH_2CH_2HgI)_2$. Iodine changes them to *Glycol Iodohydrin* (p. 319) and *β-Diiodo-ether*, $O(CH_2CH_2I)_2$. Alkaline stannic solutions react with mercury ether bromide producing *Mercury Diethylene Oxide*, $O(CH_2.CH_2)_2Hg$, m.p. 145°, a very stable compound, which requires fuming hydrochloric acid to decompose it, generating ethylene (B. **33**, 1641; **34**, 1385, 2910).

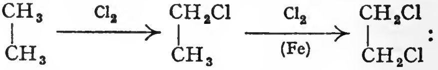
Neutral Haloid Esters of the glycols are very important parent bodies for the preparation of the glycols (comp. methods 1 and 4 for the formation of glycols, p. 309).

Methods of Formation.—(1) By the addition of halogens to the olefines—*e.g.*, ethylene gives rise to ethylene chloride, bromide and iodide:



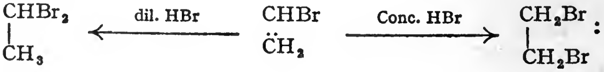
$$\begin{array}{c}CH_2\\ \|\\ CH_2\end{array}+Cl_2=\begin{array}{c}CH_2Cl\\ |\\ CH_2Cl\end{array};\quad \begin{array}{c}CH_2\\ \|\\ CH_2\end{array}+Br_2=\begin{array}{c}CH_2Br\\ |\\ CH_2Br\end{array};\quad \begin{array}{c}CH_2\\ \|\\ CH_2\end{array}+I_2=\begin{array}{c}CH_2I\\ |\\ CH_2I\end{array}:$$

(2) by substitution in paraffins and monohalogen paraffins:



$$\begin{array}{c}CH_3\\ |\\ CH_3\end{array}\xrightarrow{Cl_2}\begin{array}{c}CH_2Cl\\ |\\ CH_3\end{array}\xrightarrow[(Fe)]{Cl_2}\begin{array}{c}CH_2Cl\\ |\\ CH_2Cl\end{array}:$$

(3) by the addition of halogen acids to monohalogen olefines. In this instance much will depend on the temperature, concentration, and other conditions, as to whether both or only one of the two possible isomers is formed:

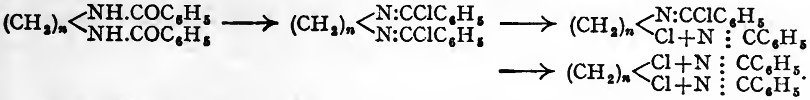


$$\begin{array}{c}CHBr_2\\ |\\ CH_3\end{array}\xleftarrow{\text{dil. HBr}}\begin{array}{c}CHBr\\ \|\\ CH_2\end{array}\xrightarrow{\text{Conc. HBr}}\begin{array}{c}CH_2Br\\ |\\ CH_2Br\end{array}:$$

(4) by the action of HCl, HBr or HI on glycols and glycol halohydrins. The second OH group will be replaced with more difficulty, and at a higher temperature, than the first. Similarly, the glycol ethers (p. 316) are converted into the dihalides by an excess of halogen acid.

(5) Alkylene diamines or halogen alkyl monoamines yield alkylene dihalides, either by the action of nitrosyl chloride or bromide (C. 1899, I. 25); or better by warming the benzoyl derivative of the amide

with phosphorus chloride or bromide, and distilling the resulting imide chloride or bromide (*v. Braun*, B. **38**, 2346; **39**, 4112):



$$(CH_2)_n\!<\!\begin{matrix}NH.COC_6H_5\\NH.COC_6H_5\end{matrix} \longrightarrow (CH_2)_n\!<\!\begin{matrix}N{:}CClC_6H_5\\N{:}CClC_6H_5\end{matrix} \longrightarrow (CH_2)_n\!<\!\begin{matrix}N{:}CClC_6H_5\\Cl+N\,\vdots\,CC_6H_5\end{matrix}$$

$$\longrightarrow (CH_2)_n\!<\!\begin{matrix}Cl+N\,\vdots\,CC_6H_5\\Cl+N\,\vdots\,CC_6H_5\end{matrix}.$$

The benzoyl derivatives of the cyclic imines, such as benzoyl piperidine, benzoyl pyrrolidine (comp. p. 335), yield dichloro- and dibromo-paraffin and benzonitrile by breakage of the ring, under the action of PCl_5 or PBr_5. This constitutes a convenient method of preparing 1,5-dichloro- and dibromopentane.

(6) by the action of PCl_5 on glycols:

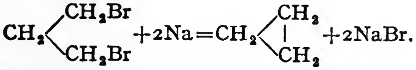
(7) by the action of KI on alkylene bromides, producing iodides; and $HgCl_2$, producing chlorides.

Properties.—The simple dichlor- and dibrom-esters of the glycols, or olefine dichlorides and dibromides, volatilize without decomposition. The di-iodides decompose readily in the light, and when distilled break down into olefines and iodine. The ethylene dihalides have a very pleasant odour.

Reactions.—(1) The dihalogen paraffins are converted into olefines by sodium:

$$\begin{matrix}CH_2Cl\\|\\CH_2Cl\end{matrix}\ \text{and}\ \begin{matrix}CHCl_2\\|\\CH_3\end{matrix}\xrightarrow{2Na}\begin{matrix}CH_2\\\|\\CH_2\end{matrix}.$$

The production of *trimethylene* from trimethylene bromide and sodium or zinc is noteworthy:



$$CH_2\!<\!\begin{matrix}CH_2Br\\CH_2Br\end{matrix}+2Na=CH_2\!<\!\begin{matrix}CH_2\\|\\CH_2\end{matrix}+2NaBr.$$

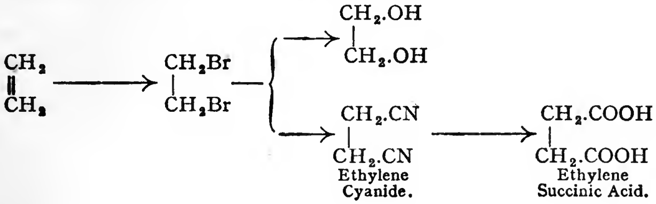
(2) Nascent hydrogen converts both di- and mono-halogen paraffins into paraffins. This is the reverse of substitution—*retrogressive substitution* (p. 93).

(3) When digested with alcoholic potassium hydroxide, halogen hydride splits off, acid molecules are lost, and monohalogen olefines and acetylenes or diolefines result (p. 86).

(4) Suitable reagents change dihalogen paraffins into the corresponding glycols (p. 309) or their esters. Heating with water produces first the mono-halogen hydrines of the glycols, and finally ketones and aldehydes. The 1,4- and 1,5-dihalides yield also cyclic oxides (comp. M. **23**, 64; C. 1902, I. 628; II. 19; 1903, I. 384).

(5) Ammonia produces alkylene diamines.

(6) Potassium cyanide converts them into the nitriles of monohalogen acids and of the dicarboxylic acids. These are classes of bodies whose connection with the glycols is indicated by the dihalogen paraffins:



(7) The alkylene dihalides react with magnesium in ethereal solution in part similarly to, and in part in a more complicated manner than, do the simple alkyl halides (p. 185). Ethylene bromide gives ethylene and magnesium bromide; in the cold $BrCH_2CH_2MgBr$ is also obtained. Trimethylene bromide forms trimethylene $(CH_2)_3$ (p. 321), and also $BrMg[CH_2]_6MgBr$, which with CO_2 yields suberic acid, $HO_2C.[CH_2]_6$-CO_2H. Pentamethylene bromide yields, as expected, $BrMg[CH_2]_5MgBr$, and also some $BrMg[CH_2]_{10}MgBr$. The latter substance, with CO_2, gives decane dicarboxylic acid; the former, pentane dicarboxylic acid (pimelic acid) and hexamethylene ketone (B. **38**, 1296; **40**, 3049; C. 1907, II. 681).

$$[CH_2]_5{<}\begin{matrix}COOH\\COOH\end{matrix} \xleftarrow{2CO_2} BrMg[CH_2]_5MgBr \xrightarrow{CO_2} [CH_2]_5{>}CO.$$

Pimelic Acid. Hexamethylene Ketone.

Ethylene Halides—Ethylene Chloride, *Elayl Chloride, Oil of the Dutch chemists*, $CH_2Cl.CH_2Cl$, b.p. 84°, $D_4 = 1{\cdot}2808$, can be prepared (A. **94**, 245) by conducting ethylene into a gently heated mixture of 2 parts of manganese dioxide, 3 parts of sodium chloride, 4 parts of water and 5 parts of sulphuric acid. It is also prepared from ethylene diamine and NOCl; also from dibenzoyl ethylene diamine and PCl_5 (comp. p. 320). It is insoluble in water, has an agreeable odour, and sweet taste.

Ethylene Bromide, $CH_2Br.CH_2Br$, m.p. 9°, b.p. 131°, is formed when ethylene is introduced into bromine, contained in a wide condenser bent at right angles, which is covered with a layer of water (A. **168**, 64). It is also produced when ethyl bromide, bromine and iron wire are heated to 100° (B. **24**, 4249).

Ethylene Iodide, $CH_2I.CH_2I$, m.p. 81°, is formed on conducting ethylene into a paste of iodine and ethyl alcohol (J. **1864**, 345).

History of the Alkylene Halides.—The four Dutch chemists, *Deiman, Paets van Troostwyk, Bondt* and *Lauwerenburgh*, while studying the action of chlorine on ethylene, first obtained ethylene chloride in 1795 as an oily reaction product. Hence they called ethylene "gaz huileux," *oily gas*, a name which *Fourcroy* altered to "gaz olefiant," "*oil-forming gas*" (see *Roscoe* and *Schorlemmer*, Org. Ch., 1, 647). This phrase subsequently gave the name "*olefines*" to the series. *Balard*, the discoverer of bromine, obtained ethylene bromide in 1826 by allowing bromine to act on ethylene (A. chim. phys. [2] **32**, 375). *Faraday*, in 1821, prepared ethylene iodide by acting on ethylene with iodine in sunlight.

Propylene Halides, 1,2-*Dihalogen Propane*, $CH_3CHX.CH_2X$, and **Trimethylene Halides**, 1,3-*Dihalogen Propane*, $CH_2X.CH_2CH_2X$. The propylene halides result from the addition of halogens to propylene, and halogen acids to alkyl halides at 100°. Trimethylene bromide is prepared from ethyl bromide and hydrobromic acid at −20° and, accompanied by propylene bromide, from trimethylene and bromine in hydrobromic acid (C. 1899, I. 731; 1900, II. 465). $HgCl_2$ and KI, change trimethylene bromide into the chloride and iodide.

Propylene Chloride, b.p. 97°;	Trimethylene Chloride, b.p. 119°.
,, Bromide, ,, 141°;	,, Bromide, ,, 165°.
,, Iodide, decomposes;	,, Iodide, decomposes.

Tetramethyl Ethylene Chloride, $(CH_3)_2CCl.CCl(CH_3)_2$, m.p. 159°, is prepared from pinacone and HCl (C. 1900, II. 1061).

Tetramethyl Ethylene Bromide, m.p. 149°, with decomposition, results from the action of sunlight on *Tetramethyl Ethylene Nitrosobromide*, $(CH_3)_2CBr.$-$C(NO)(CH_3)_2$. This substance is prepared from tetramethyl ethylene and NOBr (comp. p. 327) (B. **37**, 545). It is a very volatile *blue* crystalline powder.

1,3-*Dibromobutane*, $CH_3CHBr.CH_2CH_2Br$, b.p. 147°, is obtained from *d*-butylene glycol (C. 1902, II. 1097).

2,4-*Dibromopentane*, $CH_3CHBr.CH_2CHBrCH_3$, b.p.$_9$ 63° (C. 1904, I. 1327).

Higher Homologues of the Polymethylene Halide Series are mostly obtained by the general methods of preparation, Nos. 4 and 5 (p. 320) (J. pr. Ch. [2] **39**, 542; B. **27**, R. 735; **38**, 2346; **39**, 1112; C. 1903, I. 583; 1904, II. 429; 1905, I. 1698; 1906, I. 443).

Tetramethylene Chloride, $Cl[CH_2]_4Cl$, b.p. 162°; *bromide*, m.p. —20°, b.p.$_{12}$ 82°; *iodide*, m.p. 5·8°.

Pentamethylene Chloride, 1,5-*Dichloropentane*, $Cl[CH_2]_5Cl$, b.p. 177°; *bromide*, b.p. 221°; *iodide*, m.p. 9°, b.p.$_{20}$ 149°.

Hexamethylene Chloride, $Cl[CH_2]_6Cl$, b.p. 204°; *iodide*, m.p. 9·5°, b.p.$_{17}$ 163°.

Heptamethylene Chloride, $Cl(CH_2)_7Cl$, b.p.$_{28}$ 126°; *iodide*, m.p. 0°, b.p.$_{20}$ 178°.

2,5-*Dibromohexane*, $CH_3CHBr.CH_2.CH_2.CHBrCH_3$, is prepared from 2,5-hexylene glycol (p. 315), from Δ^a-hexane-ϵ-ol (butallyl methyl carbinol), or from diallyl (p. 190) by means of hydrobromic acid. A mixture of stereoisomeric forms is obtained, containing a *racemic* form, m.p. 38°, and the mesoform, a liquid, b.p.$_{20}$ 100° (B. **34**, 2569; **35**, 1337).

Sodium converts these compounds into cycloparaffins (Vol. II.), just as sodium and trimethylene bromide produce trimethylene. Sodium malonic esters, sodium acetoacetic esters, and polymethylene bromides produce cycloparaffin carboxylic esters (Vol. II.). Mixed, neutral halogen esters of the glycols, containing two different halogen atoms, are also known.

(*b*) Esters of Mineral Acids containing Oxygen.

Ethylene Nitrate, *Glycol Dinitrate*, $C_2H_4(O.NO_2)_2$, $D_8=1{\cdot}483$, is produced on heating ethylene iodide with silver nitrate in alcoholic solution, or by dissolving glycol in a mixture of concentrated sulphuric and nitric acids:

$$C_2H_4(OH)_2+2HO.NO_2=C_2H_4(O.NO_2)_2+2H_2O.$$

This reaction is characteristic of all hydroxyl compounds (polyhydric alcohols and polyhydric acids); the hydrogen of hydroxyl is replaced by the NO_2*-group.*

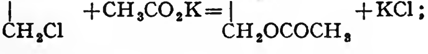
The nitrate is a yellowish liquid, insoluble in water. It explodes when heated (like nitroglycerine). Alkalis saponify the ester with formation of nitric acid and glycol.

Glycol Sulphuric Acid, $C_2H_4{<}\begin{smallmatrix}OH\\O.SO_2.OH\end{smallmatrix}$, is produced on heating glycol with sulphuric acid. It is perfectly similar to ethyl sulphuric acid (p. 139), and decomposes, when boiled with water or alkalis, into glycol and sulphuric acid.

B. Esters of Carboxylic Acids.

In studying the fatty acids the methods of forming esters with monohydric alcohols were described. The same methods serve for the production of esters of the fatty acids with dihydric alcohols or glycols:

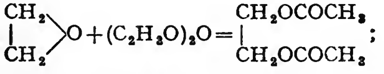
(1) from the haloid esters of the glycols: halogenhydrins and alkylene halides with fatty-acid salts:



$$\begin{array}{l}CH_2OH\\|\\CH_2Cl\end{array}+CH_3CO_2K=\begin{array}{l}CH_2OH\\|\\CH_2OCOCH_3\end{array}+KCl;$$

(2) from glycols by means of free acids, acid chlorides or acid anhydrides.

(3) There also remains that type of ester formation resulting from the addition of acids and acid anhydrides to alkylene oxides, just as acid anhydrides add themselves to aldehydes:



$$\begin{array}{l}CH_2\\|\\CH_2\end{array}\!\!>O+(C_2H_3O)_2O=\begin{array}{l}CH_2OCOCH_3\\|\\CH_2OCOCH_3\end{array};$$

$$CH_3CHO+(C_2H_3O)_2O=CH_3.CH(OCOCH_3)_2.$$

Glycol Diformin, $C_2H_4(O.CHO)_2$, b.p.$_{25}$ 89°, is prepared from glycol by a mixture of formic acid and acetic anhydride (C. 1900, II. 314).

Glycol Monacetate, $CH_2(OH)CH_2OCOCH_3$, b.p. 182°, is a liquid miscible with water. If hydrochloric acid gas be led into the warmed substance there is formed *Glycol Chloracetin*, *Chlorethyl Acetate*, $CH_2ClCH_2.O.C_2H_3O$, b.p. 144°.

Similarly, hydrobromic acid produces *Glycol Bromacetate,* b.p. 163°, which yields *Glycol Iodacetin,* b.p.$_{80}$ 110°, when treated with NaI (C. 1901, I. 1356).

Glycol Diacetate, $C_2H_4(O.C_2H_3O)_2$, b.p. 186°, $D_0=1{\cdot}128$. It dissolves in 7 parts of water. *Glycol Distearate,* $C_2H_4(OCOC_{17}H_{35})_2$, m.p. 79°, b.p.$_0$ 241°. *Glycol Dipalmitate,* $C_2H_4(OCOC_{15}H_{31})_2$, m.p. 72°, b.p.$_0$ 226° (B. **36,** 4340).

a-Propylene Glycol Diacetate, $CH_3.C_2H_3(O.COCH_3)_2$, b.p. 186°; *Trimethylene Glycol Diacetate,* $(CH_2)_3(OCOCH_3)_2$, b.p. 210°.

The formation of the acid esters is well suited for the detection and determination of the number of hydroxyl groups in the polyhydric alcohols, the sugars and the phenols. Benzoic ester particularly is especially easy to prepare. It is only necessary to shake up the substance with benzoyl chloride and sodium hydroxide in order to benzoylize all the hydroxyls (B. **21,** 2744; **22,** R. 668, 817). The formation of the *nitric acid ester* is also well adapted for the purpose (see Glycol Dinitrate, p. 323); also the *carbamic ester* resulting from the action of the isocyanic ester (*q.v.*); and especially the phenyl isocyanic ester (*q.v.*).

For carboxylic esters of unsaturated glycols, see p. 315.

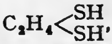
3. THIO-COMPOUNDS OF ETHYLENE GLYCOLS

Compare the sulphur derivatives of the monohydric alcohols (p. 142), the aldehydes (p. 208), and the ketones (p. 225).

A. **Mercaptans.**

The mercaptans corresponding with ethylene glycol are formed by treating monochlorhydrin and ethylene bromide with potassium hydrosulphide.

The **Monothio-ethylene Glycol,** $HSCH_2.CH_2OH$, yields isethionic acid (p. 325) when treated with nitric acid.

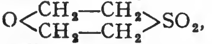
Dithioglycol, *Ethylene Mercaptan, Ethylene Thiohydrate,*  $C_2H_4<\begin{matrix}SH\\SH\end{matrix}$, b.p. 146°, D=1·12, possesses an odour something like that of mercaptan. It is insoluble in water, and dissolves in alcohol and ether. It shows the reactions of a mercaptan (B. **20,** 461).

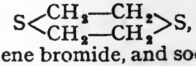
Trimethylene Mercaptan, $HS(CH_2)_3SH$, b.p. 169° (B. **32,** 1370).

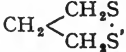
B. **Sulphides.**

(*a*) *Alkyl Ethers of the Ethylene Mercaptans: Hydroxyethyl Ethyl Sulphide,* $CH_3CH_2.S.CH_2CH_2OH$, b.p. 184°. *Ethylene Dimethyl Sulphide,* $CH_3S.CH_2.CH_2.SCH_3$, b.p. 183°. *Ethylene Diethyl Sulphide,* b.p. 188°.

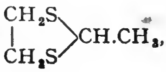
(*b*) *Vinyl-alkyl Ethers of Ethylene Mercaptan* or *Sulphuranes: Vinyl Ethyl Ethylene Mercaptan,* $CH_2{:}CH.SCH_2CH_2S.C_2H_5$, b.p. 214°. For its formation, see the *sulphine compounds,* which are treated later on.

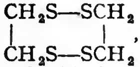
(*c*) **Thiodiglycol,** $HOCH_2CH_2.S.CH_2CH_2OH$, corresponding with diglycol, is also known (B. **19,** 3259). However, the simple ethylene sulphide, corresponding with ethylene oxide, is not known, whilst *Diethylene Oxide Sulphone,*  $O<\begin{matrix}CH_2-CH_2\\CH_2-CH_2\end{matrix}>SO_2$, m.p. 130°, corresponding with diethylene oxysulphide, as well as **Diethylene Disulphide,** are known.

(*d*) *Cyclic Sulphides:* **Diethylene Disulphide,**  $S<\begin{matrix}CH_2-CH_2\\CH_2-CH_2\end{matrix}>S$, m.p. 112°, b.p. 200°, is formed from ethylene mercaptan, ethylene bromide, and sodium oxide. When ethylene bromide is digested with alcoholic sodium sulphide, a *polymeric ethylene sulphide,* $(C_2H_4S)_n$, m.p. 145°, is produced at first. This is a white, amorphous powder, insoluble in the ordinary solvents, which protracted boiling with phenol changes to diethylene disulphide (A. **240,** 305; B. **19,** 3263; **20,** 2967).

Trimethylene Disulphide,  $CH_2<\begin{matrix}CH_2S\\ \vdots\\ CH_2S\end{matrix}$, m.p. 75° (B. **32,** 1370).

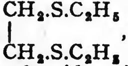
(*e*) *Ethylene Mercaptals* and *Ethylene Mercaptols* are similarly produced from ethylene mercaptan by the action of aldehydes, ketones, and HCl, just as the mercaptals (p. 209) and the mercaptols (p. 226) are obtained from mercaptans (B. **21,** 1473).

Ethylene Dithioethylidene,  $\begin{matrix}CH_2S\\ |\\ CH_2S\end{matrix}>CH.CH_3$, b.p. 173°.

(*f*) *Diethylene Tetrasulphide*,  $\begin{array}{l}CH_2S\text{—}SCH_2\\ |\qquad\quad\ |\\ CH_2S\text{—}SCH_2\end{array}$, m.p. 150°, is produced by the action of the halogens, or sulphuryl chloride or hydroxylamine on ethylene mercaptan. It is a white, amorphous powder (B. **21**, 1470).

C. Sulphine Derivatives.

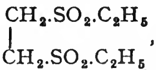
Ethyl iodide and diethylene disulphide unite to form *Diethylene Disulphide Sulphine Ethyl Iodide*,  $S{<}\begin{array}{l}CH_2\text{—}CH_2\\ CH_2\text{—}CH_2\end{array}{>}S{<}\begin{array}{l}C_2H_5\\ I\end{array}$.

Ethyl Sulphurane,  $\begin{array}{l}CH_2.S.C_2H_5\\ |\\ CH_2.S.C_2H_5\end{array}$, is produced on distilling the above-mentioned iodide with sodium hydroxide. The closed ring of diethylene disulphide is broken.

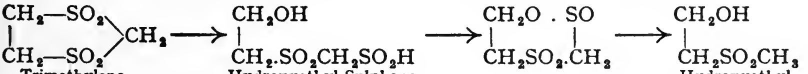
The union of the derivatives of diethylene disulphide with the higher alkyl iodides yields homologous compounds known as **sulphuranes.** They are the alkyl vinyl thio-ethers of ethylene (B. **19**, 3263; **20**, 2967; A. **240**, 305).

D. Sulphones.

The disulphones are produced when the open and the cyclic disulphides are oxidized by potassium permanganate. All sulphones, in which sulphone groups are attached to *two adjacent* carbon atoms, can be hydrolyzed (*Stuffer's* law, B. **26**, 1125).

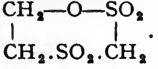
(*a*) *Open Sulphones :* **Ethylene Diethyl Sulphone**,  $\begin{array}{l}CH_2.SO_2.C_2H_5\\ |\\ CH_2.SO_2.C_2H_5\end{array}$, m.p. 137°, has been obtained (1) from ethylene dithioethyl; (2) from ethylene bromide by the action of sodium ethyl sulphinate, and (3) from sodium ethylene disulphinate by the action of ethyl bromide. The hexivalence of sulphur in the sulphones is thus proved (B. **21**, R. 102).

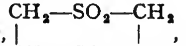
(*b*) *Cyclic Sulphones* (B. **26**, 1124; **27**, 3043): **Trimethylene Disulphone**, m.p. 204–205°, results from the oxidation of methylene dithioethylene. Barium hydroxide solution decomposes this into *Hydroxyethyl Sulphone Methylene Sulphinic Acid.* This, on boiling with water, forms first an internal *anhydride*, b.p. 164°, which then loses SO_2 and turns into *Hydroxymethylene Sulphone*, m.p. 20°.



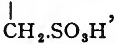
$$\begin{array}{l}CH_2\text{—}SO_2\\ |\qquad\quad\ \ {>}CH_2\\ CH_2\text{—}SO_2\end{array} \longrightarrow \begin{array}{l}CH_2OH\\ |\\ CH_2.SO_2CH_2SO_2H\end{array} \longrightarrow \begin{array}{l}CH_2O\ .\ SO\\ |\qquad\quad\ \ |\\ CH_2SO_2.CH_2\end{array} \longrightarrow \begin{array}{l}CH_2OH\\ |\\ CH_2SO_2CH_3\end{array}$$

Trimethylene Sulphone. Hydroxyethyl Sulphone Methylene Sulphinic Acid. Hydroxyethyl Methyl Sulphone.

The sulphinic lactone gives, on oxidation, *Hydroxyethyl Sulphone Methylene Sulphone Lactone*,  $\begin{array}{l}CH_2\text{—}O\text{—}SO_2\\ |\qquad\qquad\ |\\ CH_2.SO_2.CH_2\end{array}$.

Diethylene Disulphone,  $\begin{array}{l}CH_2\text{—}SO_2\text{—}CH_2\\ |\qquad\qquad\quad\ |\\ CH_2\text{—}SO_2\text{—}CH_2\end{array}$, results from the oxidation of diethylene disulphide, and decomposes similarly to trimethylene disulphone.

E. Sulphonic Acid.

Isethionic Acid, *Ethylene Hydrinsulphonic Acid, Hydroxyethyl Sulphonic Acid*,  $\begin{array}{l}CH_2.OH\\ |\\ CH_2.SO_3H\end{array}$, is isomeric with ethyl sulphuric acid, $C_2H_5O.SO_3H$, and is produced (1) by oxidizing monothioethylene glycol with HNO_3; (2) by the action of nitrous acid on taurine or amidoisethionic acid (comp. formation of glycollic acid from glycocoll, p. 362):

$$H_2N.CH_2CH_2SO_3H + HONO = HO.CH_2CH_2SO_3H + N_2 + H_2O.$$

(3) by heating glycol chlorhydrin with potassium sulphite; (4) by boiling ethionic acid (p. 327) with water (B. **14**, 64; A. **223**, 198); (5) from ethylene oxide and potassium hydrogen sulphite.

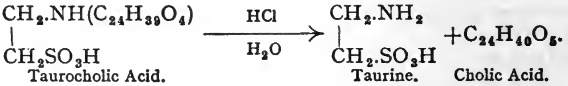
Isethionic acid is a thick liquid, which solidifies when allowed to stand over sulphuric acid. Its salts are very stable and crystallize well. Chromic acid oxidizes isethionic acid to sulpho-acetic acid.

The *barium salt* is anhydrous; *ammonium salt* forms plates, m.p. 135°, and at 210–220° it changes to the ammonium salt of *di-isethionic acid*, $O(CH_2.CH_2SO_3NH_4)_2$ (B. **14**, 65). *Ethyl Isethionate*, b.p. 120° (see B. **15**, 947).

PCl_5 converts the acid into *Chlorethyl Sulphonic Chloride*, $Cl.CH_2CH_2SO_2Cl$, b.p. 200°. It is also formed by heating ethane disulphochloride. When it is boiled with water it is converted into *Chlorethyl Sulphonic Acid*, $CH_2Cl.CH_2.SO_3H$ (A. **223**, 212).

Taurine, *Aminoisethionic Acid, Aminoethyl Sulphonic Acid,* $\begin{array}{l}CH_2NH_2\\ |\\ CH_2.SO_3H\end{array}$, or $\begin{array}{l}CH_2.NH_3\\ |\quad\ |\\ CH_2.SO_3\end{array}$, m.p. about 240°, with decomposition, was discovered by *Gmelin* in 1824; its sulphur content, which had previously been overlooked, was detected in 1846 by *Redtenbacher.* It is considered in this connection because of its intimate relationship to isethionic and chlorethylene sulphonic acids. It occurs as taurocholic acid, in combination with cholic acid, in the bile of oxen (hence the name—ταῦρος, ox) and many other animals, and also in the different animal secretions.

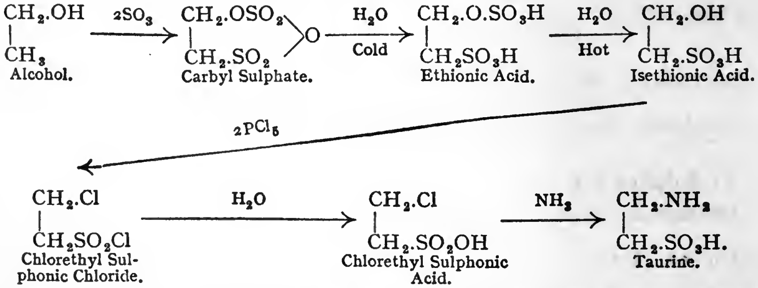
It is formed when taurocholic acid is decomposed with hydrochloric acid:



$$\underset{\text{Taurocholic Acid.}}{\begin{array}{l}CH_2.NH(C_{24}H_{39}O_4)\\ |\\ CH_2SO_3H\end{array}} \xrightarrow[H_2O]{HCl} \underset{\text{Taurine.}}{\begin{array}{l}CH_2.NH_2\\ |\\ CH_2.SO_3H\end{array}} + \underset{\text{Cholic Acid.}}{C_{24}H_{40}O_5}.$$

It can be prepared artificially by heating *chlorethyl sulphonic acid*, $CH_2ClCH_2SO_3H$, with aqueous ammonia (*Kolbe*, 1862, A. **122**, 33).

This synthesis presupposes that of ethylene or ethyl alcohol (p. 111). Both substances combine with SO_3 to give *carbyl sulphate*, a derivative of isethionic acid. The following diagram shows the course of the synthesis:



$$\underset{\text{Alcohol.}}{\begin{array}{l}CH_2.OH\\ |\\ CH_3\end{array}} \xrightarrow{2SO_3} \underset{\text{Carbyl Sulphate.}}{\left.\begin{array}{l}CH_2.OSO_2\\ |\\ CH_2.SO_2\end{array}\right\rangle O} \xrightarrow[\text{Cold}]{H_2O} \underset{\text{Ethionic Acid.}}{\begin{array}{l}CH_2.O.SO_3H\\ |\\ CH_2SO_3H\end{array}} \xrightarrow[\text{Hot}]{H_2O} \underset{\text{Isethionic Acid.}}{\begin{array}{l}CH_2.OH\\ |\\ CH_2.SO_3H\end{array}}$$

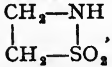
$$\xrightarrow{2PCl_5} \underset{\text{Chlorethyl Sulphonic Chloride.}}{\begin{array}{l}CH_2.Cl\\ |\\ CH_2SO_2Cl\end{array}} \xrightarrow{H_2O} \underset{\text{Chlorethyl Sulphonic Acid.}}{\begin{array}{l}CH_2.Cl\\ |\\ CH_2.SO_2OH\end{array}} \xrightarrow{NH_3} \underset{\text{Taurine.}}{\begin{array}{l}CH_2.NH_2\\ |\\ CH_2.SO_3H.\end{array}}$$

Taurine also results when *ethylenimine* is evaporated together with sulphurous acid.

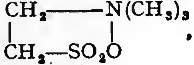
Taurine crystallizes in large, monoclinic prisms, insoluble in alcohol, but readily dissolved by hot water. It contains the groups NH_2 and SO_3H, and is, therefore, both a base and a sulphonic acid, but as the two groups neutralize each other, the compound has a neutral reaction. It may, therefore, be considered as a *cyclic ammonium salt*, as indicated in the second constitutional formula. It can form salts with the alkalis. It separates unaltered from its solution in acids (see Glycocoll).

Nitrous acid converts it into isethionic acid (p. 325). Boiling alkalis and acids do not affect it, but when fused with potassium hydroxide it breaks up according to the equation:

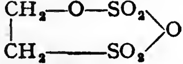
$$NH_2CH_2CH_2SO_3K + 2KOH = CH_3CO_2K + K_2SO_3 + NH_3 + H_2.$$

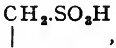
Anhydrotaurine,  $\begin{array}{l}CH_2—NH\\ |\qquad\ \ |\\ CH_2—SO_2\end{array}$, m.p. 88°, is formed by the action of ammonia on chlorethane sulphochloride, or on ethane disulphochloride (C. 1898, I. 20).

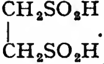
Taurine introduced into the animal economy reappears in the urine as *Taurocarbamic Acid,* $NH_2CONH.CH_2.CH_2.SO_3H$.

Taurobetaïne,  $\begin{array}{l}CH_2——N(CH_3)_3\\ |\qquad\qquad\ |\\ CH_2—SO_2O\end{array}$, is prepared by methylating taurine, and is analogous to *betaïne* (*q.v.*).

Ethionic Acid, $C_2H_4<^{O.SO_3H}_{SO_3H}$. The constitution of this acid would indicate it to be both a sulphonic acid and primary sulphuric ester. It is therefore dibasic, and on boiling with water readily yields sulphuric and isethionic acids. It results when carbyl sulphate takes up water.

Carbyl Sulphate,  $\begin{array}{l}CH_2—O—SO_2\\ |\qquad\qquad\qquad >O\\ CH_2———SO_2\end{array}$, the *anhydride* of *ethionic acid* (A. **223,** 210), is formed when the vapours of SO_3 are passed through anhydrous alcohol. It is also produced by the direct union of ethylene with two molecules of SO_3.

Ethylene Disulphinic Acid, Ethane Disulphonate,  $\begin{array}{l}CH_2.SO_3H\\ |\\ CH_2.SO_3H\end{array}$, m.p. 100°, may be prepared from glycol mercaptan and ethylene thiocyanate by means of concentrated nitric acid; by the action of fuming sulphuric acid on alcohol or ether; or by boiling ethylene bromide with a concentrated solution of potassium sulphite. It is easily soluble in water. Reduction with zinc dust, see B. **38,** 1071.

Ethane Disulphochloride, $SO_2Cl.CH_2.CH_2.SO_2Cl$, m.p. 98°, by the action of zinc dust, forms the zinc salt of *Ethylene Disulphoinic Acid,*  $\begin{array}{l}CH_2SO_2H\\ |\\ CH_2SO_2H\end{array}$. The disulphochloride, similarly to the homologous chloride of 1,2-*Propane Disulphonic Acid,* $CH_3CH(SO_2Cl)CH_2SO_2Cl$, m.p. 48°, easily gives up SO_2 (comp. p. 147, Anhydrotaurine, Vinyl, and Propenyl Sulphonic Acid); whilst the chloride of *Trimethylene Disulphonic Acid,* $CH_2(CH_2SO_2Cl)_2$, is more stable (B. **34,** 3467; **36,** 3626), and behaves in accordance with *Stuffer's* rule (p. 325).

4. NITROGEN DERIVATIVES OF THE GLYCOLS

A. Nitroso-compounds.

The addition-products of the olefines with nitrosyl chloride belong to this group (comp. the Terpenes, Vol. II.).

Tetramethyl Ethylene Nitrosyl Chloride, $(CH_3)_2C(NO).CCl(CH_3)_2$, m.p. 121°, is prepared by adding sodium nitrite to tetramethyl ethylene in an alcoholic solution of hydrochloric acid in the cold (B. **27,** 455; R. 467). It has a blue colour, and a somewhat penetrating camphor-like odour.

See also *Trimethyl Ethylene Nitrosite,* $(CH_3)_2C(ONO).CH(NO)CH_3$, and *Nitrosate,* $(CH_3)_2C(ONO_2).CH(NO)CH_3$ (p. 345).

B. Nitro-compounds.

Only one nitro-derivative of glycol—the primary body—is known. The mononitro- compounds can be looked on as being nitro-substitution products of the paraffin alcohols, and are known under the name of *nitro-alcohols*. They are prepared by the interaction of the halohydrines and silver nitrite, and from the primary mononitro- paraffins by condensation with aldehydes by means of a dilute solution of potassium bicarbonate or alkali hydroxide (C. 1899, I. 1154).

Nitroethyl Alcohol, Glycol Nitrohydrin, $CH_2(NO_2).CH_2.OH$, b.p.$_{35}$ 120°, is a heavy oil. 2-*Nitropropyl Alcohol*, $CH_3CH(NO_2)CH_2OH$, b.p.$_{22}$ 121°. *Nitroisopropyl Alcohol*, $CH_3.CH(OH)CH_2NO_2$, b.p.$_{30}$ 112°, $D_{18}=1{\cdot}191$ (B. 28, R. 606) (see also *Nitro-olefines*, p. 151). 3-*Nitropropanol*, $HO.CH_2.CH_2.CH_2NO_2$, b.p.$_{32}$ 139°. For *nitro-alcohols* containing 4,5, and 6 carbon atoms, see C. 1897, II. 337; 1898, I. 193. For *Dinitro-* and *Halogen-nitro*-compounds, corresponding with the glycol series, see pp. 151, 155.

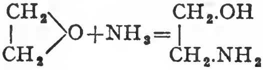
C. Amines and Ammonium Compounds of the Glycols.

There are two series of amines, derived from the glycols, and corresponding with the two series of glycollates, esters, mercaptans, etc.:

$HO.CH_2CH_2.OH$,	$HO.CH_2CH_2.NH_2$,	and	$NH_2.CH_2CH_2.NH_2$.
Glycol.	Hydroxyethylamine.		Ethylene Diamine.

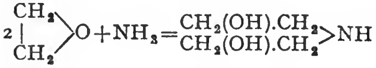
Therefore the amines of the glycols fall into two classes: (1) The hydroxyalkylamines and their derivatives; (2) the alkylene diamines and their derivatives.

(*a*) **Hydroxyalkyl Bases, or Hydramines** and their derivatives.—Methods of formation: (1) action of ammonia on the halohydrins; (2) by the union of ammonia and alkylene oxides in the presence of water (B. 32, 729; C. 1900, II. 1009). In these two reactions the products are primary, secondary, and tertiary hydroxyalkyl bases, *e.g.*:



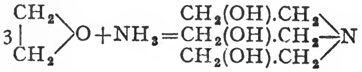
$$\begin{matrix}CH_2\\ |\\ CH_2\end{matrix}\!\!>O+NH_3=\begin{matrix}CH_2.OH\\ |\\ CH_2.NH_2\end{matrix}$$

Hydroxyethylamine or Aminoethyl Alcohol (p. 117).



$$2\begin{matrix}CH_2\\ |\\ CH_2\end{matrix}\!\!>O+NH_3=\begin{matrix}CH_2(OH).CH_2\\ CH_2(OH).CH_2\end{matrix}\!\!>NH$$

Dihydroxyethylamine or Iminoethyl Alcohol.



$$3\begin{matrix}CH_2\\ |\\ CH_2\end{matrix}\!\!>O+NH_3=\begin{matrix}CH_2(OH).CH_2\\ CH_2(OH).CH_2\\ CH_2(OH).CH_2\end{matrix}\!\!\rightarrow N$$

Trihydroxyethylamine or Azoethyl Alcohol.

These three bases are best separated by distillation under reduced pressure (B. 30, 909). They were discovered by *Würtz* and closely investigated by *Knorr*.

(3) by reduction of nitro-alcohols (see above) hydroxyacid nitriles, amino-ketones or isonitroso-ketones (B. 33, 2829, 3169);

(4) by the action of sulphuric acid on allylamine with addition of water (B. 16, 532):

(5) by the application of the phthalimide reaction (p. 159). Alkylene halides are allowed to act on potassium phthalimide, the reaction-product being heated with sulphuric acid to 200–230°:

$$C_6H_4\begin{Bmatrix}CO\\ CO\end{Bmatrix}\!\!>NK\longrightarrow C_6H_4\begin{Bmatrix}CO\\ CO\end{Bmatrix}\!\!>NCH_2.CH_2Br\longrightarrow C_6H_4\begin{Bmatrix}COOH\\ COOH\end{Bmatrix}+\begin{matrix}NH_2CH_2CH_2OH\\ HBr.\end{matrix}$$

On the course of the reaction of the alkaline decomposition of the bromalkyl phthalimides, see B. 38, 2404.

(6) The dialkylated hydroxyethylamine bases are also known as *alkamines*, and their carboxylic esters as *alkeïnes* (such as tropeïne) (B. 15, 1143). Alkamines are obtained from the halogen hydrines and

secondary amines; also from dialkyl amino-acetic esters and magnesium alkyl halides (B. **39**, 810):

$$(C_2H_5)_2N.CH_2.COOC_2H_5 \xrightarrow{C_2H_5MgI} (C_2H_5)_2N.CH_2C(C_2H_5)_2OH.$$

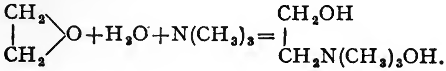
Some are possessed of physiological action (comp. C. 1904, I. 1195; 1906, I. 1584).

The hydroxyethylamine bases are separated by fractional crystallization of their HCl salts, or platinum double salts. They are thick, strongly alkaline liquids, which decompose upon distillation.

Hydroxyethylamine, Amino-ethyl Alcohol [Aminethane-2-ol] [Ethanolamine], $CH_2(OH)CH_2NH_2$, b.p. 171°, and the homologous series of the *Hydroxyethyl Alkylamines*, $CH_2(OH).CH_2(NHR)$ and $CH_2(OH)CH_2(NR_2)$, are best prepared by the addition of ammonia or the corresponding primary and secondary amines to ethylene oxide in aqueous solution (A. **315**, 104; **316**, 311). *Hydroxyethyl Dimethylamine*, $CH_2(OH).CH_2N(CH_3)_2$, is also obtained by the breaking down of methyl morphimethin (Vol. II.: Alkaloids), (B. **27**, 1144).

Choline, *Hydroxyethyl Trimethyl Ammonium Hydroxide, Bilineurine, Sincalin*, $HOCH_2.CH_2.N(CH_3)_3OH$, is quite widely distributed in the animal organism, especially in the brain, and in the yolk of egg, in which it is present as *lecithin*, a compound of choline with glycerophosphoric acid and fatty acids. It is present in hops, hence it occurs in beer. It has also been found in the plant *Strophanthus*. It is obtained, also, from sinapin (the alkaloid of *Sinapis alba*), when it is boiled with alkalis (hence the name *sincalin*). It occurs, together with *muscarine*, $(HO)_2CHCH_2N(CH_3)_3OH$(?) (B. **27**, 166), in *fly agaric* (*Argaricus muscarius*).

History.—A. Strecker discovered this base (1862) in the bile of swine and oxen. He gave it the name *choline*, from *χολή*, bile. *Liebreich* obtained it from protagon, a constituent of the nerve substance, and at first named it *neurine*, from *νεῦρον*, nerve; this he later changed to *bilineurine*, to distinguish it from the corresponding vinyl base, which continued to bear the name *neurine*. The constitution of choline was explained by *Baeyer*, and *Würtz* showed how it might be synthetically prepared by the action of trimethylamine on a concentrated aqueous solution of ethylene oxide:

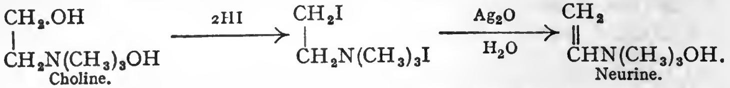


Its hydrochloride is produced from ethylene chlorhydrin and trimethylamine. Ethylene bromide and trimethylamine at 110–120° produce bromethyl trimethyl ammonium bromide, which on heating with water at 160°, gives choline hydrobromide, $HOCH_2CH_2N(CH)_3Br$ (B. **36**, 2901).

Choline deliquesces in the air. It possesses a strong alkaline reaction and absorbs CO_2. Its platinum double salt, $(C_5H_{14}ONCl)_2.PtCl_4$, crystallizes in beautiful reddish-yellow plates, insoluble in alcohol. See B. **27**, R. 738, for choline derivatives.

Isocholine, $CH_3CH(OH)N(CH_3)_3OH$, is obtained from aldehyde-ammonia (B. **16**, 207). *Homocholine*, $HOCH_2CH_2CH_2CH_2N(CH_3)_3OH$ (B. **22**, 3331).

Neurine, *Vinyl Trimethyl Ammonium Hydroxide*, $CH_2{:}CH.N(CH_3)_3OH$, resembles choline, from which it is produced when choline undergoes putrescent decomposition or when boiled with barium hydroxide solution. It has also been obtained from the brain substance. It occurs with the *ptomaïnes*—alkaloids of decay of proteïns, particularly in animal bodies. It may be derived from the bromide corresponding with choline (obtained by treating ethylene bromide with trimethylamine), and the iodide (resulting from the action of HI on choline) when they are subjected to the action of moist silver oxide:

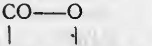


$$\begin{array}{l}CH_2.OH\\ |\\ CH_2N(CH_3)_3OH\end{array}\xrightarrow{2HI}\begin{array}{l}CH_2I\\ |\\ CH_2N(CH_3)_3I\end{array}\xrightarrow[H_2O]{Ag_2O}\begin{array}{l}CH_2\\ \|\\ CHN(CH_3)_3OH.\end{array}$$

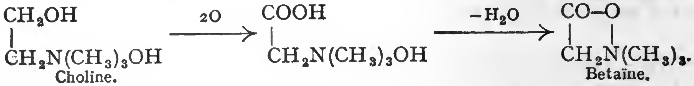
Choline. Neurine.

Contrary to choline, which is harmless, neurine is exceedingly poisonous.

Betaïne, *Trimethyl Glycocoll, Oxyneurine, Lycine,*



$\begin{array}{l}CO{-}{-}O\\ |\qquad\ \ |\\ CH_2{-}N(CH_3)_3\end{array}$, is allied to choline and neurine, from which it is obtained by oxidation (*Liebreich,* B. 2, 13):



$$\begin{array}{l}CH_2OH\\ |\\ CH_2N(CH_3)_3OH\end{array}\xrightarrow{2O}\begin{array}{l}COOH\\ |\\ CH_2N(CH_3)_3OH\end{array}\xrightarrow{-H_2O}\begin{array}{l}CO{-}O\\ |\quad\ |\\ CH_2N(CH_3)_3.\end{array}$$

Choline. Betaïne.

As it is a derivative of amino-acetic acid it will be more closely examined, in company with other betaïnes, with the amino-fatty acids.

β-Amino-ethyl Ether $C_2H_5OCH_2CH_2NH_2$, b.p. 108°, is obtained from β-chlor-or β-brom-ethylamine by means of sodium alcoholate.

β-Dimethylamine Ethyl Ether, $C_2H_5OCH_2.CH_2N(CH_3)_2$, b.p. 121°, occurs in the break-down products of various morphine bases (Vol. II.: Alkaloids) (B. **37,** 3504; **38,** 3150).

Dihydroxyethylamine, $NH(CH_2CH_2OH)_2$, m.p. 28°, b.p.$_{100}$ 270°, is prepared from ethylene oxide and dibromodiethylamine.

β-Diaminoethyl Ether, $O(CH_2CH_2NH_2)_2$, b.p. 183–184°, is obtained by the break-down of its diphthalyl derivatives, which, in turn, are prepared from diido-ether and 2 molecules of potassium phthalimide (B. **38,** 3411).

Diethyleneimide Oxide, *Morpholine,* $O{<}\begin{smallmatrix}CH_2.CH_2\\ CH_2.CH_2\end{smallmatrix}{>}NH$, is produced when dihydroxyethylamine is heated to 160° with sulphuric acid, and distilled with potassium hydroxide; also, from diiodo-ether (pp. 129, 320) and toluene sulphonamide (Vol. II.), and subsequent decomposition of the toluene sulphomorpholine formed (B. **34,** 2606). See B. **22,** 2081, for homologous morpholines. It is assumed that the same atomic grouping exists in morphine as in morpholine, hence the name.

Trihydroxyethylamine, $N(CH_2CH_2OH_3)$, b.p. 278°, *1-Amino-2-propanol,* $CH_3CH(OH).CH_2(NH_2)$, b.p. 161°; *1-Amino-2-butanol,* $CH_3CH_2CH(OH)CH_2.NH_2$, b.p. 204°, *2-Amino-3-pentanol,* $CH_3CH_2CH(OH)CH(NH_2)CH_3$, b.p. 174°, etc., are prepared by reduction from the corresponding nitro-alcohols; *1-Amino-2-propanol* and *2-Amino-3-butanol,* $CH_3CH(OH)CH(NH_2)CH_3$, also from the corresponding isonitroso-ketones; *1-Amino-2-butanol* and *2-Amino-3-pentanol* also from the corresponding amino-ketones (B. **32,** 1905; **33,** 3169; **37,** 2480; C. 1902, I. 716, 717).

1-Amino-4-butanol, $CH_2(OH).[CH_2]_2CH_2(NH_2)$, b.p. 206°, is produced from γ-cyanopropyl alcohol by sodium and alcohol (B. **33,** 3170); *methyl ether* (B. **32,** 948).

Diacetone Alkamine, $(CH_3)_2C(NH_2).CH_2CH(OH)CH_3$, b.p. 175°, results on reducing *diacetonamine* (p. 230) (A. **183,** 290; B. **30,** 1318).

For homologous *alkamines,* see also B. **14,** 1876, 2406; **15,** 1143; **28,** 3111; **29,** 1420, etc.

(*b*) **Halogen Alkylamines, or Haloid Esters of the Hydroxyalkylamines.**—In the free state these bodies are soluble in water and not very stable. They easily change to salts of the cyclic imines, *e.g.* chloramylamine, $ClCH_2(CH_2)_4NH_2$, becomes pentamethyleneimide or piperidine hydrochloride, $\overline{CH_2.(CH_2)_4NH}.HCl$. On the transformation of tert.-β- and γ-chloralkylamine into *piperazonium bromide*, see p. 337. *Methods of Formation:* (1) The addition of a halogen acid to unsaturated amines, like vinyl- or allylamine, p. 166 (B. **21**, 1055; **24**, 2627, 3220; **30**, 1124).

(2) By the action of halogen acids on hydroxyalkylamines.

(2*a*) By mixing the nitriles of the halogen substituted acids with sodium phenolate, reducing and heating with a halogen acid (B. **24**, 3221; **25**, 415):

$$Cl.CH_2CH_2CH_2CN + NaOC_6H_5 = C_6H_5O.CH_2CH_2CH_2CN + NaCl$$

$$C_6H_5OCH_2[CH_2]_2CN \xrightarrow{4H} C_6H_5.OCH_2[CH_2]_2CH_2NH_2 \xrightarrow{2HCl} ClCH_2[CH_2]_3NH_2.HCl.$$

(3) From imidochlorides, which result from the action of PCl_5 on the alkylene dibenzoyl diamines (p. 321), by distillation under reduced pressure (B. **38**, 2346).

(4) When the halogen alkyl phthalimides are heated with halogen acids (B. **21**, 2665; **22**, 2220; **23**, 90), *e.g.*:

$$C_6H_4\left\{\begin{matrix}(1)CO\\(2)CO\end{matrix}\right.\!>N.CH_2CH_2Br \xrightarrow[2H_2O]{HBr} C_6H_4\left\{\begin{matrix}(1)CO_2H\\(2)CO_2H\end{matrix}\right. + BrCH_2.CH_2NH_2.HBr.$$

Bromethyl Phthalimides. **o-Phthalic Acid.**

The following are known:

Chlor-, brom-, iodo-ethylamine, $ICH_2CH_2NH_2$; transformation of bromethylamine into ethylene imide, see p. 355. *β-Chlorethyl Dimethylamine*, $ClCH_2CH_2N.(CH_3)_2$, b.p. 110°, is an oil. Its aqueous solution changes on keeping or evaporation into tetramethyl piperazonium chloride (p. 336) (B. **37**, 3507). *β-Bromopropylamine*, $CH_3CHBrCH_2NH_2$, results from boiling allyl mustard oil with hydrobromic acid, and is obtained as a hydrobromide (B. **32**, 367). *γ-Chloropropyl Dimethylamine*, $ClCH_2CH_2CH_2N(CH_3)_2$, b.p. 135° (B. **39**, 1420). *γ-Bromopropylamine*, $BrCH_2CH_2CH_2NH_2$. *β-Bromobutylamine*, $CH_3CH_2CHBrCH_2NH_2$. *γ-Chlorobutylamine*, $CH_3CHCl.CH_2CH_2NH_2$ (B. **28**, 3111). *δ-Chlorobutylamine*, $ClCH_2[CH_2]_2.NH_2$. *ε-Chloroamylamine*, $ClCH_2[CH_2]_4NH_2$. *β-Methyl-ε-chloro-*n*-amylamine*, $CH_2Cl[CH_2]_2CH(CH_3)CH_2NH_2$. *β-*n*-Propyl-ε-chloro-*n*-amylamine*, $CH_2Cl[CH_2]_2CH(C_3H_7)CH_2NH_2$ (B. **27**, 3509; **28**, 1197). The four last compounds lose HCl and form tetramethylene imine and pentamethylene imine (p. 336); or piperidine, pipecoline, and β-propyl piperidine.

6-*Chlorohexylamine*, $Cl[CH_2]_6NH_2$, and 7-*Chloroheptylamine*, $Cl[CH_2]_7NH_2$, with 5-chloroamylamine, are obtained from the alkylene dibenzimide chlorides (method above), and, like it, yield a cyclic imide (p. 334).

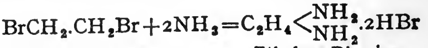
Dibromodiethylamine, $NH(CH_2CH_2Br)_2$ (B. **30**, 809).

(*c*) **Sulphur derivatives of Hydroxyethylamine.** *Aminoethyl Mercaptan Hydrochloride*, $HCl.NH_2.CH_2CH_2SH$, m.p. 71°. *Thiodiethylamine*, $(NH_2CH_2CH_2)_2S$, b.p. 232° (comp. Ethylene Imine, p. 335). *Diaminoethyl Disulphide Hydrochloride*, $(NH_2CH_2CH_2S).2HCl$, m.p. 253°. *Diaminodiethyl Sulphone*, $(NH_2CH_2CH_2)_2SO_2$, and *Diaminosulphonal*, $(NH_2.CH_2CH_2SO_2)_2C(CH_3)_2$, m.p. 85°, are prepared from bromethyl phthalimide (B. **22**, 1138; **24**, 1112, 2132, 3101; **35**, 1372).

Taurine, *Aminoisethionic Acid*, $NH_2CH_2CH_2SO_3H$, has already been discussed under isethionic acid (p. 325).

II. Alkylene Diamines.—The di-, like the monovalent alkyls, can replace two hydrogen atoms in two ammonia molecules and produce primary, secondary, and tertiary *diamines*. These are di-acid bases, and are capable of forming salts by direct union with two equivalents of acids. Some of them have been detected with the *ptomaines* or alkaloids of decay (B. **20**, R. 68) and are therefore worthy of note, *e.g.* tetramethylene diamine, and pentamethylene diamine or *cadaverine*.

Formation : (1) They are prepared by heating the alkylene bromides with alcoholic ammonia to 100° (p. 157) in sealed tubes :

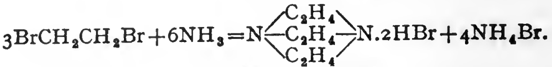


$$BrCH_2.CH_2Br + 2NH_3 = C_2H_4 < \begin{matrix} NH_2 \\ NH_2 \end{matrix} .2HBr$$

Ethylene Bromide. Ethylene Diamine.

$$2BrCH_2CH_2Br + 4NH_3 = NH < \begin{matrix} CH_2.CH_2 \\ CH_2.CH_2 \end{matrix} > NH.2HBr + 2NH_4Br$$

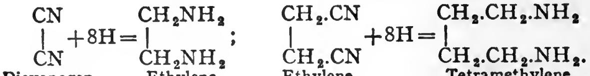
Diethylene Diamine.



Triethylene Diamine.

To liberate the diamines, the mixture of their hydrobromides is distilled with KOH and the product is then fractionated.

(2) Another very convenient method for the preparation of diamines is the reduction of (*a*) alkylene dicyanides or nitriles of dicarboxylic acids (*q.v.*) with metallic sodium and absolute alcohol (see p. 158 and B. **20,** 2215) :



$$\begin{matrix} CN \\ | \\ CN \end{matrix} + 8H = \begin{matrix} CH_2NH_2 \\ | \\ CH_2NH_2 \end{matrix} ; \quad \begin{matrix} CH_2.CN \\ | \\ CH_2.CN \end{matrix} + 8H = \begin{matrix} CH_2.CH_2.NH_2 \\ | \\ CH_2.CH_2.NH_2. \end{matrix}$$

Dicyanogen. Ethylene Diamine. Ethylene Cyanide. Tetramethylene Diamine.

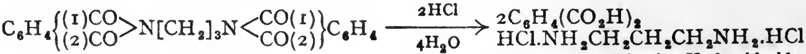
(*b*) By the reduction of the oximes, (*c*) of the hydrazones of the dialdehydes and diketones, and (*d*) of the dinitroparaffins.

In some of these reductions cyclic imines have been observed ; thus, in the reduction of ethylene cyanide in the presence of tetramethylene diamine, tetramethylene imine is formed.

(3) From dicarboxylic amides, bromine and alkali hydroxide (B. **27,** 511) (p. 159).

(4) From dicarboxylic azides (J. pr. Ch. [2], **82,** 189).

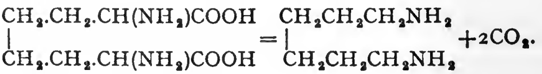
(5) From alkylene diphthalimides on heating with HCl:



$$C_6H_4\left\{\begin{matrix} (1)CO \\ (2)CO \end{matrix}\right> N[CH_2]_3N \left< \begin{matrix} CO(1) \\ CO(2) \end{matrix} \right\} C_6H_4 \xrightarrow[4H_2O]{2HCl} \begin{matrix} 2C_6H_4(CO_2H)_2 \\ HCl.NH_2CH_2CH_2CH_2NH_2.HCl \end{matrix}$$

Trimethylene Diphthalimide. Trimethylene Diamine Hydrochloride.

(6) From diamino-mono- and -di- carboxylic acid, by dry distillation (C. 1905, II. 463) :

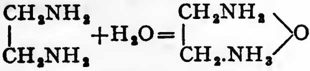


$$\begin{matrix} CH_2.CH_2.CH(NH_2)COOH \\ | \\ CH_2.CH_2.CH(NH_2)COOH \end{matrix} = \begin{matrix} CH_2CH_2CH_2NH_2 \\ | \\ CH_2CH_2CH_2NH_2 \end{matrix} + 2CO_2.$$

Properties.—The alkylene diamines are liquids or low melting solids of peculiar odour, which, in the case of those that are volatile, resembles that of ammonia, and recalls that of piperidine. They fume slightly in the air, and absorb carbon dioxide. It is found that the melting points of the homologous series are not regular in their increase, but those of members containing an even number of C atoms are higher than of those containing an uneven number. The boiling points, on the other hand, show a regular increase (J. pr. Ch. [2] **62,** 192 ; C. 1901, I. 610).

Reactions.—Alcohol and acid radicals can be introduced into the amino-groups of the diamines in the same manner as in the amino-groups of the monamines (Action of formaldehyde, see B. **36,** 35). The production of the dibenzoyl derivatives, *e.g.* $C_2H_4(NHCOC_6H_5)_2$, upon shaking with benzoyl chloride and sodium hydroxide, and the formation of phenyl ureas, $(CH_2)_n(NHCOC_6H_5)_2$, by the action of phenyl cyanate, is well adapted for the detection of the diamines (B. **21,** 2744 ; C. 1905, I. 274). On the conversion of the alkylene dibenzoyl diamines into chloralkylamines and alkylene dichlorides, see p. 320. Nitrous acid converts them into glycols, at the same time unsaturated alcohols and unsaturated hydrocarbons arise (B. **27,** R. 197).

Further, the diamines unite directly with water, forming very stable ***ammonium*** *oxides*, which only give up water again when they are distilled over potassium hydroxide (comp. Pentamethylene Diamine):



$$\begin{array}{l}CH_2NH_2\\ |\\ CH_2NH_2\end{array} + H_2O = \begin{array}{l}CH_2NH_3\\ |\\ CH_2.NH_3\end{array}\!\!>O$$, Ethylene Diamine Hydroxide.

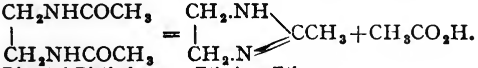
By loss of ammonia they pass into cyclic imines.

Ethylene Diamine, $C_2H_4<\begin{array}{l}NH_2\\ NH_2\end{array}$, m.p. 8·5°, b.p. 116·5°, combines with water to form *Ethylene Diamine Hydroxide*, m.p. 10°, and b.p. 118°. It reacts strongly alkaline, and has an ammoniacal odour.

Nitrous acid converts it into ethylene oxide. *Ethylene Dinitramine*, $NO_2NHCH_2.CH_2NHNO_2$ (B. **22**, R. 295). *Thionyl Ethylene Diamine*, $SO:N.CH_2.CH_2.N:SO$, m.p. 5°, b.p.$_{25}$ 100° (B. **30**, 1009).

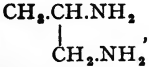
Ethylene diamine and *αβ*-propylene diamine, like the orthodiamines of the benzene series, combine with orthodiketones, *e.g.* phenanthraquinone and benzil, to form pyrazine derivatives, similar in structure to the quinoxalines. They also unite with the benzaldehydes and benzoketones (B. **20**, 276; **21**, 2358). The action on ethylene diamine of $CSCl_2$ (B. **27**, 1663), and of aldehydes (C. 1899, I. 594; B. **40**, 881).

Diacetyl Ethylene Diamine, m.p. 172°, consists of colourless needles. When this compound is heated beyond its melting point, water splits off, and there follows an inner condensation that leads to the formation of a cyclic *amidine base*, closely allied to the *glyoxalines*. It is *ethylene ethenyl amidine* or *methyl glyoxalidine*, which under the name *Lysidine*, m.p. 105°, b.p. 223°, has been recommended as a solvent for uric acid (B. **28**, 1176). The corresponding propylene and trimethylene diamine derivatives react similarly (B. **36**, 338):



$$\begin{array}{l}CH_2NHCOCH_3\\ |\\ CH_2NHCOCH_3\end{array} = \begin{array}{l}CH_2.NH\\ |\\ CH_2.N\end{array}\!\!\!\begin{array}{l}\diagdown\\ \diagup\!\!\!\diagup\end{array}\!CCH_3 + CH_3CO_2H.$$

Diacetyl Diethylene Diamine. Ethylene Etheny Amidine.

Propylene Diamine,  $\begin{array}{l}CH_3.CH.NH_2\\ \quad|\\ \quad CH_2.NH_2\end{array}$, b.p. 119–120° (B. **21**, 2359), has been resolved into optically active components by means of d-tartaric acid.

l-**Propylene Diamine,** $[\alpha]_D = -19{\cdot}11°$, forms a d-tartrate, which is sparingly soluble (B. **28**, 1180).

Trimethylene Diamine, $CH_2<\begin{array}{l}CH_2.NH_2\\ CH_2.NH_2\end{array}$, b.p. 135–136° (B. **17**, 1799; **21**, 2670), has been prepared by general methods 1, 3, and 4 (from glutaric diazide), and (2*d*) by reduction of 1,3-dinitropropane (p. 155).

αγ-**Trimethyl Trimethylene Diamine** *βδ-Diamino-β-methylpentane*, $(CH_3)_2C(NH_2)CH_2CH(NH_2)CH_3$, is obtained from diacetone amino-oxime (p. 230) by reduction with sodium amalgam (M. **23**, 9); also by reduction of acetyl acetone dioxime with sodium and alcohol. By the second method a *labile α*-diaminopentane, b.p.$_{20}$ 47°, is produced which is converted into the *stable β*-diaminopentane, b.p.$_{12}$ 44°, by prolonged boiling with alkalis. Both bases yield cyclic ethenyl amidines when heated with acetic acid (see above) (B. **32**, 1191).

Tetramethylene Diamine, 1,4-*Diaminobutane*, $NH_2[CH_2]_4NH_2$, m.p. 27°, is obtained from ethylene cyanide by general methods 2*a* and 2*b* from succinaldehyde dioxime (p. 355) (B. **22**, 1970; **40**, 3872). It is found during cystinuria in the urine and fæces. With regard to its identity with *putresceïne* (which is produced during putrescence), see B. **40**, 3875. *Tetramethyl Tetramethylene Diamine*, $(CH_3)_2N.[CH_2]_4.N(CH_3)_2$, b.p. 169°, occurs in *Hyocyamus*, Henbane (B. **40**, 3869).

1,4-*Diaminopentane*, $CH_3CH(NH_2)CH_2CH_2CH_2NH_2$, b.p. 172°, is formed from the nitrile of pyroracemic acid according to method of formation 2*a*.

2,5-*Diaminohexane*, $CH_3CH(NH_2)CH_2.CH_2CH(NH_2)CH_3$, b.p. 175°, is formed from the diphenylhydrazone of acetonyl acetone (p. 356) according to method of formation 2*c*. It exists in two forms which are characterized by their dibenzoyl derivatives: *α*-derivative, m.p. 238°; *β*-derivative, m.p. 183–185°.

They bear a relation to each other similar to that shown by racemic acid and mesotartaric acid (B. **28**, 379).

1,4-*Diamino-2-methyl Pentane*, $CH_3CH(NH_2)CH_2.CH(CH_3)CH_2NH_2$, b.p. 175°, is obtained from α-methyl lævulindialdoxime (p. 355) according to method of formation 2*b* (B. **23**, 1790).

Pentamethylene Diamine, *Cadaverine*, 1,5-*Diaminopentane*, $NH_2CH_2.CH_2.CH_2.CH_2CH_2NH_2$, b.p. 178–179°, is obtained by the reduction of trimethylene cyanide (method of formation 2*a*) (B. **18**, 2956; **19**, 780); also from pentamethylene diphthalimide (by method of formation 5) (Preparation, see B. **37**, 3583); and further, from lysine (1,5-diaminocaproic acid) (mode of formation 6, p. 332). It forms a hydrate containing $2H_2O$ (B. **27**, R. 580). It is identical with *cadaverine*, a ptomaine isolated from decaying corpses (B. **20**, 2216, and R. 69).

Neuridine, $C_5H_{14}N_2$ (B. **18**, 86), formed by the decay of fish and meat, is isomeric with pentamethylene diamine.

Hexamethylene Diamine, 1,6-*Diaminohexane*, $NH_2[CH_2]_6NH_2$, m.p. 42°, b.p.$_{20}$ 100°, is formed in the hydrolysis of *Hexamethylene Diethyl Urethane*, $[CH_2]_6(NHCO_2C_2H_5)_2$, m.p. 84°, which results upon boiling the suberic acid azide with alcohol (J. pr. Ch. [2] **62**, 206). Also from 1,6-diaminosuberic acid by distillation (mode of formation 6, p. 332); further, by reduction and hydrolysis of ε-benzoylaminocaproic acid nitrile, $C_6H_5CONH[CH_2]_5CN$ (B. **38**, 2204).

Heptamethylene Diamine, $NH_2(CH_2]_7NH_2$, m.p. 29°, b.p. 224°, is prepared from azelaïc amide and KBrO, and from pimelic nitrile by reduction (B. **38**, 2204).

1,8-*Diamino-octane*, $CH_2NH_2[CH_2]_6CH_2NH_2$, m.p. 51°, b.p. 226°, is obtained from the amide or azide of sebacic acid (method of formation 3 or 4) (J. pr. Ch. [2] **62**, 227); and from 1,8-diaminosebacic acid (method of formation 6, p. 332). Its hydrochloride gives α-butyl pyrrolidine on heating (C. 1906, II. 527).

1,9-*Diamino-nonane*, m.p. 37°, b.p. 258°, is obtained from azelaïc nitrile (*q.v.*) (C. 1897, II. 849).

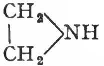
1,10-*Dekamethylene Diamine*, $NH_2CH_2(CH_2)_8CH_2.NH_2$, m.p. 61·5°, b.p.$_{12}$ 140°, results from the nitrile of sebacic acid (method of formation 2*a*) (B. **25**, 2253).

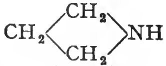
Cyclic Alkylene Imines.

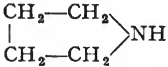
Two classes of these substances are known—the *alkylene monimines*, which contain one imino-group, and the *dialkylene diimines*, which contain two alkylene residues and two imino-groups.

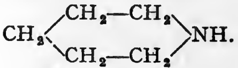
I. Alkylene Monimines.

To this group belong compounds corresponding with the alkylene oxides:

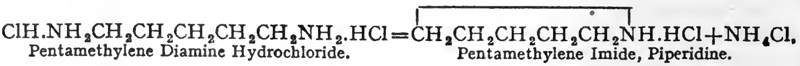

Dimethylene Imine
Ethylene Imine.


Trimethylene
Imine.


Tetramethylene
Imine.


Pentamethylene
Imine.

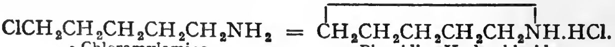
Methods of Formation.—(1) Upon heating the diamine hydrochlorides, when ammonia splits off as ammonium chloride, *e.g.*:



$$ClH.NH_2CH_2CH_2CH_2CH_2CH_2NH_2.HCl = CH_2CH_2CH_2CH_2CH_2NH.HCl + NH_4Cl.$$

Pentamethylene Diamine Hydrochloride. Pentamethylene Imide, Piperidine.

(2) By the splitting-off of halogen acid from the halogen alkyl amines—*e.g.* when the hydrochloride is heated, or when it is digested with dilute potassium hydroxide (B. **24**, 3231; **25**, 415):



$$ClCH_2CH_2CH_2CH_2CH_2NH_2 = CH_2CH_2CH_2CH_2CH_2NH.HCl.$$

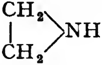
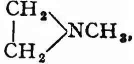
ε-Chloramylamine. Piperidine Hydrochloride.

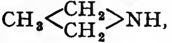
(3) They are produced, together with the diamines, in the reduction of alkylene dicyanides.

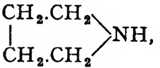
The tendency to form imino-rings and the stability of such rings towards reagents producing cleavage, depends on the number of members taking part in their structure, as has been seen to be the case among the ethylene oxides (p. 317).

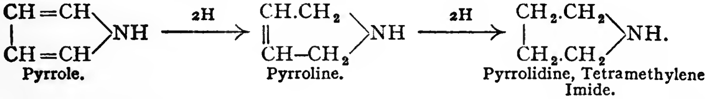
Whilst ethylene imine is easily decomposed (see below), the tetra- and penta-methylene imines are very stable, and special methods are required to break them open. Such are: (1) the *iodomethylate* method, which breaks the quaternary ammonium iodides into olefine dialkyl amines by means of alkali; (2) *oxidation of the benzoyl imines,* which produces benzoyl amino-fatty acids; (3) heating *benzoyl amines with phosphoric halides,* forming dihalogen paraffins and benzonitrile (comp. p. 321). These methods will be discussed under Heterocyclic Compounds (Vol. II.).

The investigation of the *hexa-, hepta,* and *deca-methylene imines* leaves it rather doubtful as to whether these ring-systems can exist; it appears, however, that the hydrochloride of octomethylene diamine can be prepared by heating decamethylene diamine, with the partial atomic rearrangement to form α-alkyl pyrrolidine (see below) (comp. B. **39,** 2193, 4110; C. 1906, II. 527).

Ethylene Imine, *Dimethylene Imine,*  $\left.\begin{array}{l}CH_2\\|\\CH_2\end{array}\right>NH$, b.p. 55°, $D_{20}=0{\cdot}8321$, is obtained from bromethylamine by means of Ag_2O or potassium hydroxide solution. It is a water-clear liquid, which smells strongly of ammonia, dissolves in water, and acts corrosively on the skin. It is stable against permanganate and bromine, which shows that the above formula is correct rather than the earlier vinyl formula which was assigned to it. With benzene sulphochloride (Vol. II.) and alkali, it forms a *sulphamide,* insoluble in alkali. It combines with hydrobromic acid in the cold to form bromethylamine, with H_2S to thiodiethylamine, and with sulphurous acid to taurine. n-*Methyl Ethylene Imine,*  $\left.\begin{array}{l}CH_2\\|\\CH_2\end{array}\right>NCH_3$, b.p. 28°, is prepared from chlorethyl methylamine, $ClCH_2CH_2NHCH_3$, and alkali. Similarly to ethylene imine, it is converted by iodomethane into iodo-ethyl trimethyl ammonium iodide, $ICH_2CH_2N(CH_3)_2I$ (B. **34,** 3544).

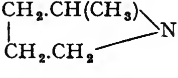
Trimethylene Imine,  $CH_3<^{CH_2}_{CH_2}>NH$, b.p. 63°, $D_{20}=0{\cdot}8436$. If trimethylene bromide and alkali react on *p*-toluol sulphamide, p-toluol sulphotrimethylene imide is produced; and when this is hydrolyzed by sodium in amyl alcohol solution, trimethylene imide is produced. It is easily decomposed by acids, as is ethylene imine (B. **32,** 2031).

Tetramethylene Imine, *Tetrahydropyrrole, Pyrrolidine,*  $\left.\begin{array}{l}CH_2.CH_2\\|\\CH_2.CH_2\end{array}\right>NH$, b.p. 87°, is obtained from tetramethylene diamine (method of formation 1); from δ-chlorbutylamine and potassium hydroxide (method 2) (B. **24,** 3231), and by the reduction of pyrroline, the first reaction-product of pyrrole (B. **18,** 2079), and of *succinimide* (see Succinic Acid) (B. **32,** 951):



$$\left.\begin{array}{l}CH=CH\\|\\CH=CH\end{array}\right>NH \xrightarrow{2H} \left.\begin{array}{l}CH.CH_2\\\|\\CH-CH_2\end{array}\right>NH \xrightarrow{2H} \left.\begin{array}{l}CH_2.CH_2\\|\\CH_2.CH_2\end{array}\right>NH.$$

Tetramethylene imide has an odour resembling that of piperidine. *Tetramethylene Nitrosamine,* C_4H_8NNO, b.p. 214° (B. **21,** 290). n-*Methyl Pyrrolidine,* $(CH_2)_4NCH_3$, b.p. 82°, is produced by distillation of tetramethyl tetramethylene diamine dichloromethylate (p. 333).

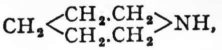
1- or α-*Methyl Pyrrolidine,*  $\left.\begin{array}{l}CH_2.CH(CH_3)\\|\\CH_2.CH_2\end{array}\right>NH$, b.p. 79°, is obtained from γ-valerolactam (*q.v.*).

2- or β-*Methyl Pyrrolidine,* b.p. 103° (B. **20,** 1654).

1,4-*Dimethyl Pyrrolidine,* b.p. 107° (B. **22,** 1859).

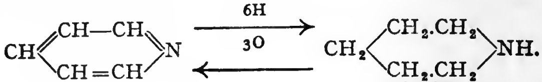
1,4-*Tetramethyl Pyrrolidine* (C. 1905, II. 830).

Pentamethylene Imine, *Piperidine, Hexahydropyridine,*



$$CH_2{<}\begin{matrix}CH_2.CH_2\\ CH_2.CH_2\end{matrix}{>}NH,$$

b.p. 106°, is obtained according to methods 1, 2 (B. **25,** 415) and 3 (p. 334); also from piperine (Vol. II.), and by the reduction of pyridine, into which it passes when it is oxidized:



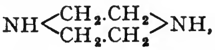
Pyridine. Piperidine.

Piperidine bears the same relation to pyridine that is sustained by pyrrolidine to pyrrole. Therefore, tetramethylene imide and pentamethylene imide link the pyrrole and pyridine groups to the simple aliphatic substances, the diamines, and their parent bodies, the glycols. The pyrrole and pyridine derivatives will be discussed later in connection with the heterocyclic ring systems, together with allied bodies, and pyrrolidine and piperidine will again be referred to.

II. Dialkylene Diimines.

This class embraces those compounds corresponding with diethylene oxide (p. 316), diethylene disulphide (p. 324), and diethylene imido-oxide or morpholine (p. 330).

Diethylene Diimine, *Piperazine, Hexahydropyrazine,*



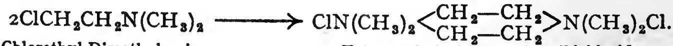
$$NH{<}\begin{matrix}CH_2.CH_2\\ CH_2.CH_2\end{matrix}{>}NH,$$

m.p. 104°, b.p. 145°, was first prepared by the action of ammonia on ethylene chloride. It is produced by heating ethylenediamine hydrochloride (B. **21,** 758), and by the reduction of *pyrazine,* $N{\lessgtr}\begin{matrix}CH{=}CH\\ CH{-}CH\end{matrix}{\gtrless}N$ (B. **26,** 724). It is technically made from *diphenyl diethylene diamine,* the reaction-product of aniline and ethylene bromide, when it is converted into the p-dinitroso-compound, and the latter then broken down into p-dinitrosophenol and diethylene diamine:

$$C_6H_5N{<}\begin{matrix}[CH_2]_2\\ [CH_2]_2\end{matrix}{>}NC_6H_5 \rightarrow NOC_6H_4N{<}\begin{matrix}[CH_2]_2\\ [CH_2]_2\end{matrix}{>}N.C_6H_4NO \rightarrow NH{<}\begin{matrix}CH_2.CH_2\\ CH_2.CH_2\end{matrix}{>}NH$$

Diethylene diamine, or piperazine, is a strong base, soluble in water, which upon distillation with zinc dust, changes to *pyrazine* (Vol. II.) (B. **26,** R. 441). It is important that piperazine unites with uric acid to form a salt even more readily soluble than the lithium salt. Hence its strongly alkaline, dilute solution has been recommended as a solvent for uric acid (B. **24,** 241). For piperazine derivatives, see B. **30,** 1584.

Quaternary Piperazonium Halides are obtained by the action of iodo-alkyls on piperazine (B. **36,** 145); and also by spontaneous change of β-chlor- or brom-ethyl dialkylamines (p. 331) whereby the oily bases are converted into solid neutral salts:



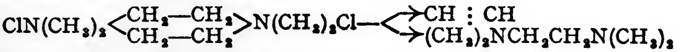
$$2ClCH_2CH_2N(CH_3)_2 \longrightarrow ClN(CH_3)_2{<}\begin{matrix}CH_2{-}CH_2\\ CH_2{-}CH_2\end{matrix}{>}N(CH_3)_2Cl.$$

Chlorethyl Dimethylamine. Tetramethyl Piperazonium Dichloride.

Alkali produces ethylene methylimine and the polymeric n-*dimethyl piperazine,* whilst chlor- and brom-ethylamine yield only ethyleneimine.

Dipiperidyl Piperazonium Bromide, $\begin{matrix}(CH_2)_5 \\ Br\end{matrix}\!\!>\!N\!<\!\begin{matrix}CH_2-CH_2 \\ CH_2-CH_2\end{matrix}\!>\!N\!\lessgtr\!\begin{matrix}(CH_2)_5 \\ Br\end{matrix}$, is obtained, analogously to the above, from β-bromethyl piperidine, $(CH_2)_5NCH_2$-CH_2Br. It is also prepared from piperazine and two molecules of dibromopentane.

These quaternary piperazonium halides are decomposed by alkalis partly into acetylene and tetra-alkyl ethylene diamines:



$$ClN(CH_3)_2\!<\!\begin{matrix}CH_2-CH_2 \\ CH_2-CH_2\end{matrix}\!>\!N(CH_3)_2Cl \longrightarrow \begin{cases}\rightarrow CH:CH \\ \rightarrow (CH_3)_2NCH_2CH_2N(CH_3)_2\end{cases}$$

and partly into hydroxethyl dialkylamines.

Dry distillation decomposes tetramethyl piperazonium chloride into chloromethane and n-dimethyl piperazine (B. **37**, 3507; **38**, 3136; **40**, 2936).

Trimethylene Ethylene Diimine, $NH\!<\!\begin{matrix}CH_2-CH_2 \\ CH_2-CH_2-CH_2\end{matrix}\!>\!NH$, b.p. 169°, is prepared from trimethylene ethylene p-toluene sulphimide,

$$C_7H_7SO_2N\!<\!\begin{matrix}CH_2-\!\!-\!\!-CH_2 \\ CH_2CH_2CH_2\end{matrix}\!>\!NSO_2C_7H_7$$

and HCl (B. **32**, 2041; **33**, 761).

Bis-Trimethylene Diimine, $NH\!<\!\begin{matrix}CH_2CH_2CH_2 \\ CH_2CH_2CH_2\end{matrix}\!>\!NH$, m.p. 15°, b.p. 187°, is obtained from its p-toluene sulphimide, which is the product of reaction between trimethylene bromide and the di-sodium salt of di-p-toluene sulphotrimethylene diamide, $CH_3C_6H_4SO_2NNa.CH_2CH_2CH_2.NNaSO_2C_6H_4CH_3$ (B. **32**, 2038).

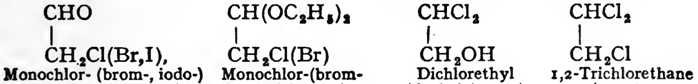
The spontaneous change of γ-chloropropyl dimethylamine, $ClCH_2CH_2CH_2N$-$(CH_3)_2$, produces *Bis-trimethylene Tetramethyl Diimonium Chloride*, $Cl(CH_3)_2N$-$[CH_2CH_2CH_2]_2N(CH_3)_2Cl$ (comp. above, piperazonium bromide; and B. **39**, 1420).

2. ALDEHYDE-ALCOHOLS

These contain both an alcoholic hydroxyl group and the aldehyde group CHO, hence their properties are both those of alcohols and aldehydes (p. 191). The addition of 2 H-atoms changes them to glycols, whilst by oxidation they yield the hydroxy acids, containing a like number of carbon atoms. The most important representatives of this group are the β-hydroxyaldehydes or *aldols*, which result from the *aldol condensation* of the simple aldehydes.

Glycollic Aldehyde, [Ethanolal], $CH_2(OH)CHO$, m.p. 95–98°, is the first aldehyde of glycol, and can be obtained from it by oxidation with hydrogen peroxide in the presence of ferrous salts. It is also prepared from bromacetaldehyde and barium hydroxide solution, and from chloracetal by treatment with alkali followed by acid (C. 1903, I. 1427). Further, it is very easily produced from dihydroxymaleïc acid (an oxidation product of tartaric acid) by heating it with water at 50–60°. A noteworthy formation, although only in small quantities, is that by condensation of formaldehyde by means of $CaCO_3$ (B. **39**, 50). Glycollic aldehyde remains behind, when its solution evaporates, as a slightly sweet syrup; this can be distilled under reduced pressure, when it solidifies; on melting it undergoes condensation very easily. Bromine water oxidizes it to glycollic acid (p. 362), whilst it is condensed by sodium hydroxide solution to *tetrose* (*q.v.*), and by sodium carbonate solution to *acrose* (*q.v.*) (B. **25**, 2552, 2984; C. 1899, II. 88; 1900, I. 285). Hydroxylamine gives rise to an oily oxime (C. 1900, II. 312), and phenylhydrazine and acetic acid produce glyoxal osazone (p. 356).

The following *derivatives of glycol aldehyde* have already been discussed:



$$\begin{array}{l} CHO \\ | \\ CH_2Cl(Br,I), \end{array} \qquad \begin{array}{l} CH(OC_2H_5)_2 \\ | \\ CH_2Cl(Br) \end{array} \qquad \begin{array}{l} CHCl_2 \\ | \\ CH_2OH \end{array} \qquad \begin{array}{l} CHCl_2 \\ | \\ CH_2Cl \end{array}$$

Monochlor- (brom-, iodo-) acetaldehyde (p. 203). Monochlor-(bromacetal (p. 205). Dichlorethyl Alcohol (p. 117). 1,2-Trichlorethane (p. 95).

Glycol Acetal, $CH_2OH.CH(O.C_2H_5)_2$, b.p. 167°, is obtained from bromacetal (B. **5**, 10).

Glycol Dimethyl Acetal, $CH_2OH.CH(OCH_3)_2$, b.p. 158°, is produced from glycol aldehyde by hydrochloric acid in methyl alcoholic solution (B. **39**, 3053). *Ethoxyacetal*, $C_2H_5O.CH_2CH(OC_2H_5)_2$, b.p. 168°, is prepared from 1,2-dichlorether (p. 129), or from chlor- or brom-acetal and sodium alcoholate. Greatly diluted sulphuric acid or a molecular proportion of water in acetone solution produces *Ethoxyacetaldehyde*, $C_2H_5O.CH_2CHO$, b.p. 71–73° (B. **39**, 2644; C. 1905, I. 1219; 1907, I. 706). *Phenoxyacetal*, $C_6H_5O.CH_2.CH(OC_2H_5)_2$, b.p. 257° (B. **28**, R. 295).

α-Hydroxypropionaldehyde, $CH_3CH(OH)CHO$, is unknown. *α-Acetoxypropionaldehyde*, b.p.$_{15}$ 52–55°, is formed when α-iodopropionaldehyde and silver acetate react. Heated with water to 100°, acetol (Hydroxyacetone, p. 1) is formed. It is also obtained when α-bromopropionaldehyde is heated with potassium formate and methyl alcohol, instead of the expected α-hydroxypropionaldehyde (A. **335**, 266). *Dichlorisopropyl Alcohol*, $Cl_2CHCH(OH)CH_3$, b.p. 147°, can be looked on as a derivative of α-hydroxypropionaldehyde. It is prepared from dichloraldehyde and CH_3MgBr (B. **40**, 27).

α-Hydroxybutyl Aldehyde, $(CH_3)_2C(OH).CHO$, b.p. 137°, is prepared from *α-Bromoisobutyl Aldehyde*, b.p. 113°, and water. It is an easily polymerizable liquid. Sodium hydroxide solution converts it into isobutylene glycol (p. 313) and α-hydroxybutyric acid, a reaction which other aldehydes undergo (M. **21**, 1122).

β-Hydroxypropionaldehyde, Hydracrylic Aldehyde, $HOCH_2.CH_2CHO$, b.p.$_{18}$ 90°, is produced when acroleïn is heated with water to 100°: *semicarbazone*, m.p. 114°, regenerates acrolein when treated with bisulphate. It easily polymerizes. Alkali partially converts it to crotonaldehyde (A. **335**, 219). *β-Hydroxypropionacetal*, $OHCH_2.CH_2.CH(OC_2H_5)_2$, b.p.$_{20}$ 98°, is prepared by prolonged boiling of dilute sodium hydroxide solution at 115° with *β-Chloropropionacetal*, b.p.$_{20}$ 74°, the addition product of acroleïn acetal (p. 213) and HCl (B. **33**, 2760). *Isotriethylin*, $CH_3CH(OC_2H_5)CH(OC_2H_5)_2$, or possibly $CH_2(OC_2H_5).CH(OC_2H_5)_2$, b.p.$_{16}$ 81°, results when acroleïn and alcohol are heated together at 50° for several days; and also by the action of orthoformic ether on acroleïn (B. **31**, 1014).

Aldol, *β-Hydroxybutyraldehyde*, $CH_3.CH(OH).CH_2.CHO$, b.p.$_{12}$ 60–70°, $D_0=1{\cdot}120$, was discovered by *Würtz* in 1872. It is obtained by the condensation of acetaldehyde by means of dilute cold hydrochloric acid, and other condensation agents, *e.g.* K_2CO_3 (B. **14**, 2069; **24**, R. 89; **25**, R. 732; M. **22**, 59; C. 1907, I. 1400).

Aldol freshly prepared is a colourless, odourless liquid, and is miscible with water. It distils under atmospheric pressure, partially reforming acetaldehyde, but it mainly becomes converted into *crotonaldehyde* and water.

As an aldehyde it will reduce an ammoniacal silver nitrate solution. Heated with silver oxide and water it yields β-hydroxybutyric acid, $CH_3.CH(OH).CH_2.CO_2H$.

After prolonged standing aldol polymerizes, becoming viscous, sometimes depositing crystals of *Paraldol*, $(C_4H_8O_2)_2$, m.p. 80–90° (M. **21**, 80). If, during the preparation of aldol, the mixture of aldehyde and hydrochloric acid be left undisturbed, the aldol condenses with loss of water to *Dialdan*, $C_8H_{14}O_3$, m.p. 139°, a crystalline body which reduces ammoniacal silver solution. *Tetraldan*, $C_{16}H_{28}O_6$, is formed simultaneous with dialdan, and does not reduce silver from its ammoniacal solution (C. 1900, II. 838). *Diethyl Acetal* of *β-Ethoxybutyric Aldehyde*, $CH_3.CH(OC_2H_5)CH_2.CH(OC_2H_5)_2$, b.p.$_{14}$ 73° (B. **31**, 1014).

The *aldol condensation* is characteristic for this class of substance and occurs among the higher members of the series when a free hydrogen atom exists next to the aldehyde group. Thus, a series of β-hydroxyaldehydes or *aldols* can be prepared. A mixture of two aldehydes yields *mixed aldols*. The condensing agent mostly employed is potassium carbonate:

$$2CH_3.CH_2CHO = CH_3CH_2CH(OH)CH(CH_3)CHO$$
$$CH_2O+(CH_3)_2CHCHO = CH_2(OH)C(CH_3)_2CHO.$$

Like aldol itself, the homologous aldols are easily converted into α,β-olefine aldehydes when a hydrogen atom in the α-position is free, and are stable bodies. If, however, there is no α-hydrogen atom present, some members decompose more easily than aldol into the simple aldehyde. Aldols from isobutyric aldehyde are further acted on by hot alkali during reaction and are transformed into the corresponding glycols and isobutyric acid (p. 308) (*Lieben*, M. **22**, 289).

Formisobutyric Aldol, $CH_2(OH).C(CH_3)_2.CHO$, m.p. 90°, b.p.$_{15}$ 85°, is converted into β-dimethyl trimethylene glycol (p. 314) and α-dimethyl β-hydroxypropionic acid by the action of alkalis. *Acetopropionic Aldol*, $CH_3.CH(OH).CH(CH_3)CHO$, b.p.$_{20}$ 92°. *Propionic Aldol*, b.p.$_{23}$ 95°. *Isobutyric Aldol*, b.p.$_{17}$ 104°–109°. *Isobutyric Isovaleric Aldol* is decomposed by heat into its component parts. For other aldols, see C. 1904, I. 199; II. 1599; vapour pressure of the aldols, see M. **21**, 80.

NITROGEN-CONTAINING DERIVATIVES OF THE ALDEHYDE-ALCOHOLS

Nitroaldehydes.

Nitroacetaldehyde, NO_2CH_2CHO, has not yet been isolated. *Methazonic Acid*, formulated otherwise on p. 151, can probably be looked on as being its oxime. It is prepared from two molecules of aci-nitromethane by a kind of aldol condensation (see formation of glycol aldehyde from formaldehyde, p. 337) accompanied by loss of water:

$$\underset{\text{aci-Nitromethane.}}{HO_2N{:}CH_2+CH_2{:}NO_2H} \longrightarrow \underset{\text{Intermediate product.}}{[HO_2N{:}CH.CH_2.NO_2H]} \longrightarrow \underset{\text{Methazonic Acid.}}{HO_2N{:}CH.CHNOH}:$$

Phenylhydrazine and aniline yield respectively the *Hydrazone*, NO_2CH_2-$CH{:}N{:}NHC_6H_5$, m.p. 74°, and the *Anilide*, $NO_2CH_2CH{:}NC_6H_5$, m.p. 95° (B. **40**, 3435).

It is justifiable, on systematic grounds, to include in this section the aldol-like condensation products of aldehydes with potassium dinitromethane (p. 154):

$$CH_2O+\underset{\text{aci-Dinitromethane.}}{CH(NO_2){:}NOOH} \rightleftarrows \underset{\text{aci-Dinitro-ethyl Alcohol.}}{CH_2(OH).C(NO_2){:}NO_2H}.$$

The resulting *potassium salts* form yellow crystals, which, as such or in aqueous solution, decompose into their components on being heated. The free acids are strongly acid, easily decomposable oils. Similar condensation products, *e.g.* *α-Dinitro-alkylamines*, are also obtained from the aldehyde-ammonias or amino-compounds and dinitromethane:

$$CH_3CH(NH_2)OH+CH_2(NO_2)_2 \longrightarrow \underset{\alpha\text{-Dinitro-}\beta\text{-aminopropane.}}{CH_3.CH(NH_2)CH(NO_2)_2}$$

$$(CH_3)_2NCH_2OH+CH_2(NO_2)_2 \longrightarrow \underset{\alpha\text{-Dinitro-}\beta\text{-dimethyl Aminoethane.}}{(CH_3)_2N.CH_2.CH(NO_2)_2}.$$

These bodies are more stable, probably on account of their forming cyclic internal salts (comp. p. 327) between the acid nitro- and the amino-groups (B. **38**, 2031, 2040). Finally, formaldehyde and acetaldehyde unite with nitrobromomethane (p. 429) to form, respectively, *α-Nitrobromethyl Alcohol*, $NO_2.CHBr.CH_2OH$, b.p.$_{45}$ 147°, and *α-Nitro-bromisopropyl Alcohol*, $NO_2CHBr.$-$CH(OH)CH_3$, b.p.$_{42}$ 149° (C. 1899, I. 179).

Aldehyde-Ammonias.—Ammonia gas converts aldol in ethereal solution into aldol-ammonia, $C_4H_8O_2.NH_3$, a thick syrup, soluble in water. When heated with ammonia the bases, $C_8H_{15}NO_2$, $C_8H_{13}NO$, *oxytetraldine* (p. 215), and *collidine*, $C_5H_2N(CH_3)_3$, are formed. With aniline aldol forms *methyl quinoline*. (Comp. alkylidene anilines.)

Amidoaldehydes: Aminoacetaldehyde, [*Ethanalamine*], [2-Amino-ethanal], $NH_2.CH_2CHO$, is obtained as a deliquescent hydrochloride when *aminoacetal*, $NH_2.CH_2(OC_2H_5)_2$, b.p. 163°, is treated with cold, concentrated hydrochloric acid. Aminoacetal is produced when chloracetal is treated with ammonia (B. **25**, 2355; **27**, 3093). Aminoacetaldehyde is also obtained from alkylamine by the splitting action of ozone (comp. p. 84, etc.) (B. **37**, 612):

$$CH_2{:}CH.CH_2NH_2 \xrightarrow{O_3} CH_2O+OCH.CH_2.NH_2.$$

Aminoacetaldehyde yields *pyrazine*, $\mathrm{N{<}\substack{CH=CH\\CH=CH}{>}N}$ (B. **26**, 1830, 2207), when it is oxidized with mercuric chloride. On *Dialkyl aminoacetals* and the *Dialkyl aminoacetaldehydes* and trialkyl ammonium salts, see B. **30**, 1504.

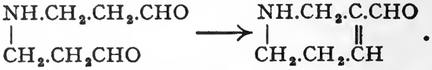
Hydrazine Acetaldehyde (B. **27**, 2203).

Betaïne Aldehyde, $\mathrm{(CH_3)_3\overline{N.CH_2CHO}(OH)}$ (?) (B. **27**, 165), is different from *Muscarine* (p. 329), which occurs in fly agaric (*Agaricus muscarius*).

Isomuscarine, $HO.CH_2CH(OH)N(CH_3)_3OH$ (?), is obtained from the addition product of HClO and neurine (p. 329) with silver oxide (A. **267**, 532, 291).

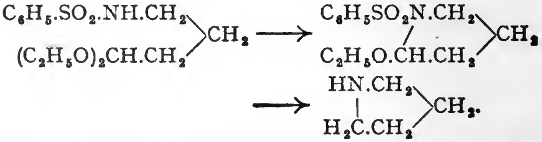
a-Aminopropionaldehyde, $CH_3CH(NH_2)CHO$, is obtained by the action of ozone on a-styryl ethylamine (B. **37**, 615).

β-Aminopropionaldehyde, $NH_2CH_2.CH_2.CHO$, is obtained as a salt by the breaking down of its *acetal*, $NH_2CH_2.CH_2CH(OC_2H_5)_2$, b.p.$_{18}$ 80°, which, in turn, is produced from β-chloropropionic acetal (p. 338), by digestion with alcoholic ammonia. At the same time there is formed *Iminodipropionic Acetal*, $HN[CH_2CH_2CH(OC_2H_5)_2]_2$, b.p.$_{15}$ 157°, which on hydrolysis yields iminodipropionic aldehyde, a substance which undergoes ring-condensation to form *β-Tetrahydropyridine Aldehyde* (B. **38**, 4162):



$$\begin{array}{l}NH.CH_2.CH_2.CHO\\ |\\ CH_2.CH_2CHO\end{array} \longrightarrow \begin{array}{l}NH.CH_2.C.CHO\\ |\qquad\quad \|\\ CH_2.CH_2.CH\end{array}.$$

γ-Aminobutyric Acetal, $NH_2.CH_2CH_2.CH_2CH(OC_2H_5)_2$, b.p. 196°, results from the reduction of β-cyanopropionic acetal by sodium and alcohol. Its *Benzene sulpho* derivatives condense spontaneously forming n-*Benzene sulpho-a-ethoxypyrrolidine*, which is reduced to *Pyrrolidine* by sodium and amyl alcohol (B. **38**, 4157):



$$\begin{array}{l}C_6H_5.SO_2.NH.CH_2\\ (C_2H_5O)_2CH.CH_2\end{array}\!\!>CH_2 \longrightarrow \begin{array}{l}C_6H_5SO_2N.CH_2\\ \quad\ /\\ C_2H_5O.CH.CH_2\end{array}\!\!>CH_2 \longrightarrow \begin{array}{l}HN.CH_2\\ \ |\\ H_2C.CH_2\end{array}\!\!>CH_2.$$

δ-Aminovaleric Aldehyde, $NH_2CH_2CH_2CH_2CH_2CHO$, and its homologues were thought to have been produced by the oxidation of piperidine (p. 336 and Vol. II.) with H_2O_2; but this is now known to be *Piperidine Oxide*, $\mathrm{CH_2{<}\substack{CH_2-CH_2\\CH_2-CH_2}{>}N{<}\substack{H\\O}}$ (B. **31**, 2687).

3. KETONE-ALCOHOLS OR KETOLS

The ketone alcohols or ketols are distinguished, according to the position of the alcohol or ketone groups, as a- or 1,2-, β- or 1,3-, γ- or 1,4-ketols, etc. The position of these two groups, with reference to each other, influences the chemical character of these bodies more than the type of alcohol group (whether primary, secondary, or tertiary). These alcohols show simultaneously the character of alcohols and of ketones.

A. SATURATED KETOLS

a- or 1,2-Ketols show tendencies to desmotropic transformations. Many of their modes of formation and reactions point to the isomeric forms of the *Olefine glycols* (p. 315) or *Hydroxyethylene oxides*. *Acetal* (p. 341) undergoes certain easily followed changes which permit of a decision being made as to which of the following four formulæ are to be assigned to it:—

$$CH_3CO.CH_2OH \quad CH_3\overline{C(OH).CH_2O} \quad CH_3C(OH){:}C(OH)H \quad CH_3CH(OH)CHO.$$

The di-acylates of the olefine glycols (p. 315) yield ketone-alcohols on hydrolysis, and some of the sodium compounds of these reproduce olefine glycol diacylates by reaction with acyl chlorides.

Phenylhydrazine and the α-ketone aldehydes yield, by oxidation, osazones of 1,2-aldehyde ketones or 1,2-diketones (comp. the Dextroses).

Acetyl Carbinol, *Pyroracemic Alcohol, Acetone Alcohol, Acetol, Hydroxyacetone,* [Propanolone], CH_3COCH_2OH, b.p. 145–146°, b.p.$_{18}$ 54°, is obtained :

(1) From chlor- or bromacetone ; or best by heating potassium formate and methyl alcohol, when the first formed acetyl formate is *alcoholyzed* by the methyl alcohol.

(2) A remarkable mode of formation is from α-bromopropionic aldehyde or α-acetoxypropionic aldehyde (see pp. 338, 340) (A. **335**, 247).

(3) From propylene glycol and the *Sorbose bacterium,* or by careful oxidation with bromine water (C. 1899, II. 475 ; 1900, I. 280).

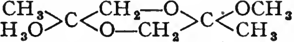
(4) If glycerol vapour is passed over pumice-stone at 430–450° some acetol is formed.

(5) When sucrose or dextrose is fused with potassium hydroxide, acetol results (B. **16**, 834).

Acetol reacts acid (comp. formula, p. 340) (C. 1905, II. 29). Reduction with aluminium amalgam yields propylene glycol (p. 313) and acetone (C. 1903, I. 132). Acetol shows a strong reducing action, and when oxidized by the oxides of Cu, Hg, Fe is converted into lactic acid, with the probable intermediate formation of pyroracemic aldehyde :

$$CH_3CO.CH_2OH \xrightarrow{O} [CH_3CO.CHO] \xrightarrow{H_2O} CH_3CH(OH)COOH.$$

Permanganate, chromic acid, and the like, oxidize acetol into acetic and formic acids (C. 1905, I. 19).

Methyl alcohol containing a trace of hydrochloric or acetic acid converts acetol into *Bis-acetol Methyl Alcholate,*  $\begin{matrix}CH_3\\CH_3O\end{matrix}\!>\!C\!<\!\begin{matrix}CH_2—O\\O—CH_2\end{matrix}\!>\!C\!<\!\begin{matrix}OCH_3\\CH_3\end{matrix}$, m.p. 130°, b.p. 196°. *Acetol Ether Ether,* $CH_3COCH_2.O.C_2H_5$, b.p. 128°, is prepared from propargyl ethyl ether (p. 129), or synthetically, from ethoxyacetonitrile, $C_2H_5OCH_2CN$ and methyl magnesium iodide. Similar *homologous ethoxymethyl alkyl ketones* (C. 1907, I. 872) may be obtained. On the formation of such ketones from halogen acetoacetic esters, see B. **21**, 2648. *Acetol Formate,* $HCOO.CH_2COCH_3$, b.p. 169°, and higher esters, see C. 1905, II. 754. *Chlor-, Brom-, Iodo-acetone* (p. 224) are the haloid esters of acetyl carbinol.

Propionyl Carbinol, *Ethyl Ketol,* $CH_3CH_2CO.CH_2OH$, b.p. 160°, is obtained from chloromethyl ethyl ketone, $ClCH_2COCH_2CH_3$; also from tetrinic acid (*q.v.*) by the loss of CO_2 on boiling with water. It is oxidized by *Fehling's* solution to α-hydroxybutyric acid (C. 1905, II. 116).

The secondary α-ketone alcohols are obtained by the two following general methods :—

(1) The esters of the fatty acids in ethereal or benzene solution and in the presence of sodium yield *acyloïns* (comp. Benzoïn, Vol. II.) through the union of the two acyl radicals (C. 1906, II. 1113) :

$$2R.COOC_2H_5+4Na \longrightarrow 2NaOC_2H_5+[R.C(ONa):C(ONa)R] \longrightarrow RCO.CH(OH)R.$$

(2) Acylates, produced by the action of sodium on the acid chlorides of the olefine glycols (p. 315) yield acyloïns on hydrolysis :

$$4RCOCl+4Na \longrightarrow 2NaCl+RC(OR):C(OR).R \xrightarrow{H_2O} R.COCH(OH)R.$$

Acetyl Methyl Carbinol, *Dimethyl Ketol, Acetoïn,* [2,3-Butanonal], $CH_3CH(OH)COCH_3$, b.p. 148°, is produced in small quantities from acetic ester in ethereal benzene solution by means of sodium. Also, from methyl chlorethyl ketone, $CH_3COCHClCH_3$; from βγ-butylene glycol (p. 313) by the action of the *Sorbose bacterium* or *Mycoderma aceti ;* and from various carbohydrates by the *Bacillus tartricus* (C. 1901, I. 878 ; 1905, II. 117 ; 1906, II. 1113). It is prepared from diacetyl (p. 349) by reduction with zinc and sulphuric acid (B. **40**, 4338). *Acetyl Ethyl Carbinol,* $CH_3CO.CH(OH)C_2H_5$, b.p.$_{35}$ 77°, is similarly obtained from acetyl propionyl (B. **23**, 2425). The sodium compound of dimethyl ketol (acetoïn) (obtained from acetic ester) when treated with acetyl chloride, yields the *Diacetate* of the *Olefine Glycol*, $CH_3C(OCOCH_3):C(OCOCH_3)CH_3$, b.p.$_{29}$ 110–115° (C. 1906, II. 1113). *Dimethyl Ketol* polymerizes spontaneously to a *dimer* $(C_4H_8O_2)_2$, m.p. 95° (B. **40**, 4336).

According to the above methods, 1 and 2, the following compounds can also be prepared: *Propionoïn*, $C_2H_5COCH(OH)C_2H_5$, b.p.$_{20}$ 73°. *Butyroïn*, b.p.$_{10}$ 85°. *Isobutyroïn*, b.p.$_{26}$ 83°. *Valeroin*, b.p.$_{12}$ 156°. *Pivaloïn*, $(CH_3)_3CCO.CH(OH)$-$C(CH_3)_3$, m.p. 81°, b.p.$_{10}$ 80°. *Capronoïn*, b.p.$_8$ 131°. These keto-alcohols are reduced by sodium and alcohol partially to the glycols and partially to secondary alcohols. Heated with finely divided copper they yield α-diketones; concentrated potassium hydroxide solution with atmospheric oxygen converts them partially to tertiary alcohol acids (comp. the ***Benzylic acid transformation***, Vol. II.) (C. 1906, II. 1114; B. **31**, 1217).

β- or 1,3-**Ketols.**

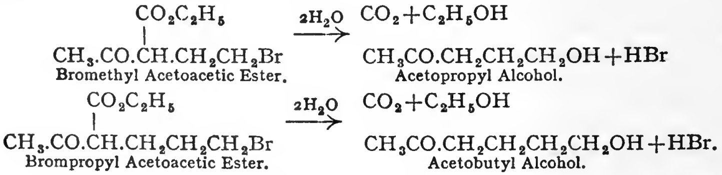
When the aldol condensation (p. 338) is carried out with aldehyde or chloral and acetone, methyl ethyl ketone and methyl isopropyl ketone by means of potassium cyanide, the following compounds result (B. **25**, 3155; C. 1897, I. 1018; 1905, II. 752): *Hydracetal Acetone*, *δ-Hydroxy-β-Ketopentane*, $CH_3CH(OH)COCH_3$, b.p. 176°. *Chloral Acetone*, $CCl_3CH(OH)CH_2COCH_3$, m.p. 75°. *Hydracetyl Ethyl Methyl Ketone*, Methyl-3-pentane-2-on-4-ol, CH_3-$CH(OH)CH(CH_3)COCH_3$, b.p. 187°. *Hydracetyl Isopropyl Methyl Ketone*, Dimethyl-3-pentane-on-2-ol-4, $CH_3CH(OH)C(CH_3)_2COCH_3$, b.p.$_{10}$ 80°, gives on oxidation meso-dimethyl acetyl acetone (p. 351).

Diacetone Alcohol, $(CH_3)_2C(OH)CH_2COCH_3$, b.p. 164°, is obtained from diacetonamine (p. 230) and nitrous acid; also when two molecules of acetone are condensed by concentrated sodium hydroxide solution at 0°. Heat reverses this reaction and the alkali breaks up the compound into acetone (Z. phys. Ch., **33**, 1129; C. 1902, II. 1096). Loss of water changes these β- or 1,3-ketols into unsaturated ketones (p. 228); *e.g.* diacetone alcohol is converted into mesityl oxide. *Mesityl Oxide Sesquimercaptol*, $(CH_3)_2C(SC_2H_5)CH_2.C(SC_2H_5)_2CH_3$, can be looked on as being a derivative of diacetone alcohol. It is prepared from mesityl oxide, mercaptan, and HCl, and is an oil. Oxidation changes it into *Trisulphone*, $(CH_3)_2C(SO_2C_2H_5).CH_2.C(SO_2C_2H_5)_2CH_3$, m.p. 100° (B. **34**, 1398). A series of further derivatives of diacetone alcohol, such as *Diacetone Hydroxylamine*, *β-Nitroso-* and *β-Nitro-isopropyl Acetone* have been dealt with (p. 231) in connection with mesityl oxide.

The *haloid esters* of the *β-ketoles* are the β-halogen ketones (p. 225), of which mention may here be made of *β-Chlorethyl Ethyl Ketone*, b.p.$_{20}$ 68°, *β-Chlorethyl Isopropyl Ketone*, b.p.$_{10}$ 73°; and *β-Chlorethyl Isobutyl Ketone*, b.p.$_{12}$ 80°, having the general formula $ClCH_2CH_2COR$, which are prepared from β-chloropropionyl chloride and zinc alkyls.

γ- or 1,4-**Ketols** and δ- or 1,5-**Ketols.**

Representatives of these are obtained from the products of reaction of ethylene bromide and trimethylene bromide on sodium acetoacetic ester, by boiling with hydrochloric acid (B. **19**, 2844; **21**, 2647; **22**, 1196, R. 572):



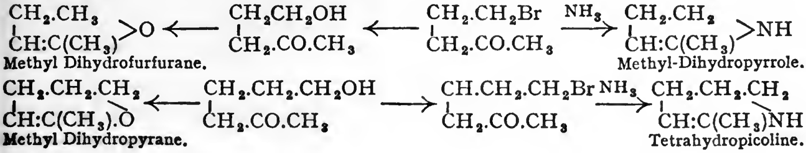
$$\underset{\text{Bromethyl Acetoacetic Ester.}}{CH_3.CO.\overset{\displaystyle CO_2C_2H_5}{\overset{|}{C}}H.CH_2CH_2Br} \xrightarrow{2H_2O} \underset{\text{Acetopropyl Alcohol.}}{\overset{\displaystyle CO_2+C_2H_5OH}{CH_3CO.CH_2CH_2CH_2OH+HBr}}$$

$$\underset{\text{Brompropyl Acetoacetic Ester.}}{CH_3.CO.\overset{\displaystyle CO_2C_2H_5}{\overset{|}{C}}H.CH_2CH_2CH_2Br} \xrightarrow{2H_2O} \underset{\text{Acetobutyl Alcohol.}}{\overset{\displaystyle CO_2+C_2H_5OH}{CH_3CO.CH_2CH_2CH_2CH_2OH+HBr.}}$$

(1) *γ-Acetopropyl Alcohol*, $CH_3.CO.CH_2CH_2CH_2OH$, b.p. 208°, with decomposition (C. 1903, II. 551).

(2) *δ-Acetobutyl Alcohol*, $CH_3.CO.CH_2CH_2CH_2CH_2OH$, decomposes about 155°.

These compounds when heated give off water and become converted into the oxides of unsaturated glycols (below). Both ketone alcohols fail to reduce an ammoniacal copper solution, but when oxidized with chromic acid yield the corresponding carboxylic acids: ***lævulinic acid*** (*q.v.*) and ***γ-acetobutyric acid*** (*q.v.*). They yield the corresponding glycols, *γ-pentamethylene glycol* and ***δ-hexamethylene glycol***, when reduced. *γ-Methyl γ-acetobutyl alcohol* (B. **32**, 61). Hydrobromic acid converts them into *bromopropyl methyl ketone*, $CH_3.CO.CH_2CH_2CH_2Br$, and *bromobutyl methyl ketone*, $CH_3.CO.CH_2CH_2CH_2CH_2Br$, b.p. 216°. These bromides are converted by ammonia into ring-shaped imides (B. **25**, 2190), similar to the γ-diketones (p. 351). This reaction links the open, aliphatic compounds with the pyrrole and pyridine derivatives:



$$\begin{matrix}CH_2.CH_3\\ |\\ CH:C(CH_3)\end{matrix}\!\!>\!O \longleftarrow \begin{matrix}CH_2CH_2OH\\ |\\ CH_2.CO.CH_3\end{matrix} \longleftarrow \begin{matrix}CH_2.CH_2Br\\ |\\ CH_2.CO.CH_3\end{matrix} \xrightarrow{NH_3} \begin{matrix}CH_2.CH_2\\ |\\ CH:C(CH_3)\end{matrix}\!\!>\!NH$$

Methyl Dihydrofurfurane. Methyl-Dihydropyrrole.

$$\begin{matrix}CH_2.CH_2.CH_2\\ |\quad\quad\quad\diagdown\\ CH:C(CH_3).O\end{matrix} \longleftarrow \begin{matrix}CH_2.CH_2.CH_2OH\\ |\\ CH_2.CO.CH_3\end{matrix} \longrightarrow \begin{matrix}CH.CH_2.CH_2Br\\ |\\ CH_2.CO.CH_3\end{matrix} \xrightarrow{NH_3} \begin{matrix}CH_2.CH_2.CH_2\\ |\quad\quad\quad\diagdown\\ CH:C(CH_3)NH\end{matrix}$$

Methyl Dihydropyrane. Tetrahydropicoline.

B. Olefine Ketols.

Methoxymesityl Oxide, $(CH_3)_2C:C(OCH_3)COCH_3$, b.p. 168°, and *Acetoxymesityl Oxide*, $(CH_3)_2C:C(OCOCH_3).COCH_3$, b.p.$_{12}$ 74°, are derived from an *olefine α-ketol*, and are prepared from bromomesityl oxide. Hydrolysis produces acetoxymesityl oxide and acetyl isobutyryl respectively (p. 349) (B. **33**, 500).

HYDROXYMETHYLENE KETONES

Compounds of this class are obtained from the ketones $R.CO.CH_3$ and $R.CO.CH_2R'$ and formic ester in the presence of sodium ethoxide, accompanied by the loss of alcohol:

$$HC\!\!<\!\!\begin{matrix}OC_2H_5\\ O\end{matrix} + CH_3COCH_3 \xrightarrow{C_2H_5ONa} CH_3COCH{=}CHONa + C_2H_5OH.$$

These substances were at first thought to be β-keto-aldehydes. However, their pronounced acid character has shown that they should be regarded as hydroxymethylene ketones, acyl vinyl alcohols (*Claisen*, B. **20**, 2191; **21**, R. 915; **22**, 533, 3273; **25**, 178). According to the later nomenclature these compounds can be described as *aci-aldehyde ketones* or aci-formyl ketones (comp. p. 40). They dissolve in alkali carbonate solutions forming stable salts, and give green coloured precipitates with copper acetate (B. **22**, 1018). Acetic anhydride and benzoyl chloride converts them in a free state as readily as the phenols into neutral acetates and benzoates, insoluble in alkalis. Their alkali derivatives and ethyl iodide yield *ethoxymethylene ketone*, which is saponified by alcoholic alkalis, like the ethers of organic carboxylic acids. These compounds, $-CO.CH{=}CH.OH$, are the first exceptions to the rule of *Erlenmeyer* (p. 37), according to which the complex $>C{=}CHOH$ present in open chains must invariably become rearranged into the *aldehyde form* $>CH.CHO$. It is shown, on the contrary, that when a hydrogen atom of the methyl or methylene group in acetaldehyde or its homologues, $R.CH_2.CHO$, is replaced by an acid radical, a rearrangement of the aldehyde form into the *vinyl alcohol form* is sure to follow (B. **25**, 1781).

In conjunction with this explanation it may be mentioned that the alkoxymethylene group—*e.g.* $C_2H_5O.CH{=}$—may be introduced by means of orthoformic ester and acetic anhydride into compounds which contain the atomic grouping, $-CO.CH_2.CO-$ (B. **26**, 2729), *e.g.* into acetyl acetone, acetoacetic ester and malonic ester. The compounds which result will be described subsequently in their proper places.

Hydroxymethylene Acetone, aci-*Formyl Acetone*, aci-*Acetoacetic Aldehyde*, $CH_3CO.CH{=}CHOH$, b.p. about 100°, readily condenses in solution to [1.3.5]-*Triacetyl Benzene*, $C_6H_3[1.3.5\text{-}](CO.CH_3)_3$ (*q.v.*). Hydrazine converts it into 3-methyl pyrazole, and phenylhydrazine into 1-phenyl 3-methyl pyrazole (*q.v.*). *Hydroxymethylene Diethyl Ketone*, $C_2H_5CO.C(CH_3){=}CHOH$, m.p. 40°, b.p. 164–166°. aci-*Diethyl Acetyl Acetaldehyde*, $(C_2H_5)_2CHCOCH:CHOH$, b.p. 174°. aci-*Trimethyl Acetyl Acetaldehyde*, $(CH_3)_3CCOCH:CHOH$, b.p. 148°. aci-*Isovaleryl Acetaldehyde*, $(CH_3)_2CH.CH_2COCH:CHOH$, b.p.$_{10}$ 52°. aci-*Isocaproyl Acetaldehyde*, $C_5H_{11}COCH:CHOH$, cannot be distilled without decomposition even *in vacuo* (C. 1905, II. 393).

NITROGEN-CONTAINING DERIVATIVES OF THE KETONE-ALCOHOLS

As in the case of the simple ketones, the ketone-alcohols can frequently be characterized through their *semicarbazones*, *oximes*, and *phenylhydrazones* (comp. pp. 227, 228). It has, however, already been pointed out that the *a*-ketols, combining with phenylhydrazine, easily yield the *osazones* of the a-diketones. The β-hydroxymethylene ketones react with hydroxylamine and hydrazine, as do the β-diketones (p. 350); forming the cyclic compounds *isoxazoles* and *pyrazoles*.

Those derivatives of the ketone-alcohols, in which the alcoholic group has been replaced by a nitrogen group, have been most conveniently collected into the following series of compounds.

1A. NITRO-KETONES

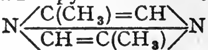
Nitroacetone, $CH_3COCH_2.NO_2$, b.p. 152°, is prepared by oxidation of nitroisopropyl alcohol (B. **32**, 865). An apparently *isomeric nitroacetone*, m.p. 49°, is obtained from iodo-acetone and silver nitrate (B. **32**, 3179); both substances are acid in character. Aniline reacts with nitroacetone (m.p. 49°) forming *Nitroacetone Anil*, $CH_3C(NC_6H_5\ CH_2NO_2$, m.p. 87°, which can also be obtained from nitrilomesityl dioxime peroxide (p. 231) and aniline acetate (A. **319**, 230). On nitroisopropyl acetone, see p. 231.

1B. **Mesohalogen Nitro-alcohols,** see p. 151.

2,2-*Chloronitropropanol*, $CH_3CCl(NO_2)CH_2OH$, m.p. 13°, b.p.$_{44}$ 115°, is prepared from 1,1-chloronitroethane and formaldehyde. 2,2-*Bromonitropropanol*, $CH_3.CBr(NO_2)CH_2OH$, m.p. 42°. 2,2-*Chloronitrobutanol*, $CH_3CH_2CCl(NO_2)CH_2OH$, b.p. 145–150° (C. 1897, II. 338; 1898 I. 194). *Trinitrotrimethyl Propane*, $(CH_3)_2C(NO_2)C(NO_2)_2CH_2CH_3$, m.p. 95°, is obtained from trimethyl propane and nitric acid (B. **32**, 1443).

(2A.) **Aminoketones** of the saturated series are produced from the chlorinated ketones by the action of ammonia or amines, from the olefine ketones by addition of ammonia and amines (mainly β-*aminoketones*), and from the isonitrosoketones by reduction with zinc chloride (a-*aminoketones*) (B. **30**, 1515; **32**, 1095).

Aminoacetone, $CH_3COCH_2NH_2$, is formed by the reduction of isonitroso acetone and of nitroacetone (m.p. 49°). Further, by the breaking up of *phthalimidoacetone* (prepared from potassium phthalimide and chloracetone), a salt of aminoacetone is obtained from which alkali liberates, not the simple base, but one of the formula $C_6H_{10}N_2$, accompanied by the elimination of water. By boiling with water, the substance is converted into aminoacetone hydrochloride (B. **38**, 752).

Aminomethyl Ethyl Ketone, $NH_2.CH_2COCH_2CH_3$, is obtained from its phthalyl derivative (B. **37**, 2474). *Aminopropyl Methyl Ketone*, $CH_3COCH(NH_2)C_2H_5$, is an oil which solidifies to a crystalline mass. *Aminomethyl Isopropyl Ketone*, $(CH_3)_2CHCOCH_2NH_2$ (B. **32**, 1201). By oxidation with mercuric chloride, for instance, these compounds yield a pyrazine derivative, *e.g.* aminoacetone is converted to *Dimethyl Pyrazine*  $N{\begin{smallmatrix}\diagup C(CH_3)=CH \diagdown\\ \diagdown CH=C(CH_3) \diagup\end{smallmatrix}}N$ (B. **27**, R. 928). The *pyrazines*, *ketines*, or *aldines* are described among the heterocyclic compounds in Vol. II. The hydrochlorides of the a-aminoketones easily react with potassium cyanate forming *imidazoles* (Vol. II.), whilst potassium thiocyanate forms *imidazolyl mercaptans* (Vol. II.) (B. **27**, 1042, 2036).

Aminosulphonal, *Aminoacetone Diethyl Sulphone*, $CH_3C(SO_2C_2H_5)_2CH_2NH_2$, m.p. 94°, results from the action of hydrochloric acid on phthalimidosulphonal, the oxidation product of phthalimidoacetone ethyl mercaptol. This, in turn, is prepared from acetonyl phthalimide ethyl mercaptan and hydrochloric acid (B. **32**, 2749).

Dialkyl Aminoketones are produced to a considerable extent from chloracetone and secondary amines. *Dimethyl Aminoacetone*, $(CH_3)_2N.CH_2COCH_3$, b.p. 123°. *Diethyl Aminoacetone*, b.p. 153° (B. **29**, 866). *Trimethyl Acetonyl Ammonium Chloride, Coprin*, $(CH_3)_3N(CH_2COCH_3)Cl$, is produced from monochloracetone and trimethylamine. Its physiological action is similar to that of curare (C. 1898, II. 631).

2B. **Olefine β-Aminoketones** are prepared from acetyl acetone (p. 350) by the action of ammonia, primary and secondary alkylamines (B. **26**, R. 295). *Acetyl Acetonamine*, $CH_3CO.CH{=}C(NH_2)CH_3$, m.p. 43°, b.p. 209°. *Acetyl Acetone Ethylamine*, $CH_3CO.CH{=}C(NHC_2H_5)CH_3$, b.p. 210–215°. *Acetyl Acetone Diethylamine*, $CH_3CO.CH{=}C[N(C_2H_5)_2].CH_3$, b.p.$_{24}$ 155°.

3. **Hydroxylaminoketones**, see Diacetone Hydroxylamine (p. 231).

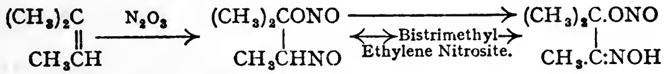
4. **α-Halogen Ketoximes** are formed by the action of hydroxylamine on monohalogen acetone (p. 224). *Chloracetoxime*, $CH_2Cl.C:N(OH).CH_3$, b.p. 71°. *Bromacetoxime*, m.p. 36°. *Iodo-acetoxime*, m.p. 64° (B. **29**, 1550).

5. **Ketoxime Amines.**

Triacetonylamine Trioxime, $N(CH_2.C:N.OH.CH_3)_3$, m.p. 184°, is prepared from chloracetoxime and ammonia (B. **31**, 2396).

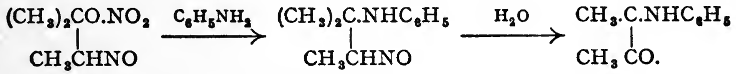
6. **Nitrosoketones**, see Nitrosoisopropyl Acetone (p. 231).

7. **Alkylene Nitrosochlorides** are prepared by the inter-action of amyl nitrite and hydrochloric acid (comp. p. 327); **Alkylene Nitrosites** from amyl nitrite and nitric acid; **Alkylene Nitrosates** from nitrogen trioxide and dioxide and alkylenes of the type $R_2C:CHR$. They are nitrogen derivatives of the α-ketoles (A. **241**, 288; **248**, 161; B. **20**, R. 638; **21**, R. 622; C. 1899, II. 176). β-Isoamylene (Trimethyl Ethylene) is primarily converted by N_2O_3 into a *true nitroso-* compound (comp. 152), a liquid showing the characteristic blue colour. On standing it *polymerizes* spontaneously to a white crystalline substance, m.p. 76°, which is depolymerized on melting. Alkalis partially convert the nitrosite into the isomeric *isonitroso-* compound, m.p. 126°, with some decomposition:



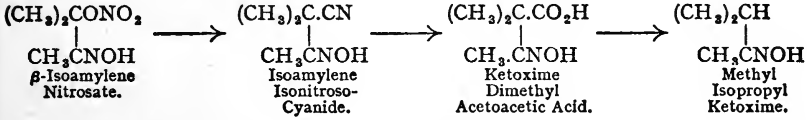
$$\begin{matrix}(CH_3)_2C\\ \|\\ CH_3CH\end{matrix} \xrightarrow{N_2O_3} \begin{matrix}(CH_3)_2CONO\\ |\\ CH_3CHNO\end{matrix} \underset{\text{Ethylene Nitrosite.}}{\overset{\xrightarrow{\hspace{2.5cm}}}{\longleftrightarrow\text{Bistrimethyl}\rightarrow}} \begin{matrix}(CH_3)_2C.ONO\\ |\\ CH_3.C{:}NOH\end{matrix}$$

Similarly, trimethyl ethylene and N_2O_4 yield a *nitrosate*, $(CH_3)_2C(ONO_2)$-$CH(NO)CH_3$, a blue liquid, spontaneously polymerizing to *Bis-trimethyl Ethylene Nitrosate*, m.p. 99°, consisting of white crystals, which on being warmed in solution become both de-polymerized and converted into the isomeric *isonitroso* compound (B. **35**, 2323). Treatment with amines causes a replacement of the $O.NO_2$ group for NHR, whereby the *nitrolamines* are formed, which pass into *keto-amines:*



$$\begin{matrix}(CH_3)_2CO.NO_2\\ |\\ CH_3CHNO\end{matrix} \xrightarrow{C_6H_5NH_2} \begin{matrix}(CH_3)_2C.NHC_6H_5\\ |\\ CH_3CHNO\end{matrix} \xrightarrow{H_2O} \begin{matrix}CH_3.C.NHC_6H_5\\ |\\ CH_3\,CO.\end{matrix}$$

The $-ONO_2$ group of the amylene nitrosate can be exchanged for CN by the action of potassium cyanide, the resulting nitrile being convertible into the *oxime*, m.p. 97°. This body decomposes into CO_2 and methyl isopropyl ketoxime, whereby its constitution is indicated:



$$\underset{\substack{\beta\text{-Isoamylene}\\ \text{Nitrosate.}}}{\begin{matrix}(CH_3)_2CONO_2\\ |\\ CH_3CNOH\end{matrix}} \longrightarrow \underset{\substack{\text{Isoamylene}\\ \text{Isonitroso-}\\ \text{Cyanide.}}}{\begin{matrix}(CH_3)_2C.CN\\ |\\ CH_3CNOH\end{matrix}} \longrightarrow \underset{\substack{\text{Ketoxime}\\ \text{Dimethyl}\\ \text{Acetoacetic Acid.}}}{\begin{matrix}(CH_3)_2C.CO_2H\\ |\\ CH_3.CNOH\end{matrix}} \longrightarrow \underset{\substack{\text{Methyl}\\ \text{Isopropyl}\\ \text{Ketoxime.}}}{\begin{matrix}(CH_3)_2CH\\ |\\ CH_3CNOH\end{matrix}}$$

Trimethyl Ethylene Nitrosochloride, $(CH_3)_2CCl.C(NO)HCH_3$, and *Trimethyl Ethylene Nitrosobromide*, $(CH_3)_2.CBrC(NO)HCH_3$, behave similarly to the nitrosites and nitrosates. They are prepared by the action of HCl and HBr respectively on a mixture of amyl nitrite and trimethyl ethylene. They easily polymerize to their colourless dimers, which pass on melting to the blue form. Prolonged heating converts them by isomerization into true colourless *halogen ketoximes*, $(CH_3)_2CCl.C(NOH)CH_3$, m.p. 50°, and $(CH_3)_2CBr.Cl(NOH)CH_3$, m.p. 79° (B. **37**, 532).

Dimethyl Ethyl Ethylene Nitrosochloride, $(CH_3)_2CCl.C(NOH)C_2H_5$, m.p. 78°. *Diethyl Methyl Ethylene Nitrosate*, $(C_2H_5)_2C(ONO_2).C(NOH)CH_3$, m.p. 81° with decomposition.

The nitrosate and nitrosite reactions assume some importance among the terpenes (Vol. II.).

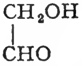
4. DIALDEHYDES

The dialdehydes, ketone aldehydes, and diketones constitute a closely united series of compounds, connected together by many characteristics. They are subdivided according to the position of the two CO groups relatively to each other: α- or 1,2-, β- or 1,3, γ- or 1,4, δ- or 1,5, diketo-compounds, of which the characteristic reactions will be described amongst the diketones (pp. 348, 355).

Glyoxal, *Oxaldehyde Diformyl* [Ethane-dial], CHO.CHO, m.p. about 15°, b.p. 51°, $D_{20}=1{\cdot}14$, was discovered by *Debus* in 1856. It is the dialdehyde of ethylene glycol and of oxalic acid, whilst glycolyl aldehyde (p. 339) represents the first or half aldehyde of ethylene glycol and the aldehyde of glycollic acid:

$$\begin{array}{c} CH_2OH \\ | \\ CH_2OH \end{array}$$

Glycol.



$$\begin{array}{c} CH_2OH \\ | \\ CHO \end{array}$$

Glycolyl Aldehyde.

$$\begin{array}{c} CHO \\ | \\ CHO \end{array}$$

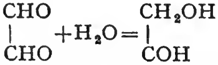
Glyoxal.

Glyoxal, glycollic acid and glyoxylic acid are formed by the careful oxidation of ethylene glycol, ethyl alcohol (B. **14,** 2685; **17,** R. 168), or acetaldehyde with nitric acid. It can also be formed from dihydroxytartaric acid by the interaction of its sodium salt and sodium bisulphite (B. **24,** 3235):

It may also be prepared from the breaking down of *αβ*-olefine aldehydes (p. 84) by ozone, as in the case of heating cinnamic aldehyde ozonide (see Vol. II.) with water.

By this means a *trimeric* glyoxal $(CHO.CHO)_3$ is obtained, whilst the other methods result in the production of a *polymeric paraglyoxal,* $(CHO.CHO)_n$ when the aqueous solution of glyoxal is evaporated. This amorphous powder melts with difficulty. When heated with P_2O_5 it is converted into the *monomolecular* glyoxal, in the form of golden yellow crystals and a yellow green vapour, with the pungent odour of formaldehyde. It dissolves in non-aqueous solvents to a yellow solution. The colours are characteristic, since *all bodies which contain the α-diketo-group*—CO.CO—*possess a more or less strongly developed colour,* usually *yellow to orange.* In a small quantity of water glyoxal polymerizes to paraglyoxal; in more water, it dissolves with a generation of heat to the monomolecular colourless *hydrate,* $HCO.CH(OH)_2$ or $(HO)_2CH.CH(OH)_2$. The aqueous solutions of the various modifications all give the same reactions, except with ***Fehling's*** solution, which is reduced only by the trimeric glyoxal (*Harries,* B. **40,** 165).

Reactions.—The alkalis convert it, even in the cold, into glycollic acid. In this change the one CHO group is reduced, whilst the other is oxidized (comp. Benzil and Benzilic Acid, Vol. II.):

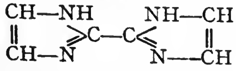


$$\begin{array}{c} CHO \\ | \\ CHO \end{array} + H_2O = \begin{array}{c} CH_2OH \\ | \\ COH \end{array}$$

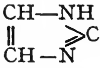
It reduces ammoniacal silver solution with the formation of a mirror, and unites with two molecules of sodium hydrogen sulphite to form a crystalline *glyoxal sodium sulphite,* $C_2H_2O_2(SO_3HNa)_2+H_2O$. Ethyl alcohol and a little HCl give rise to *Glyoxal Tetraethyl Acetal,* $(C_2H_5O)_2CH.CH(OC_2H_5)_2$, b.p.$_{14}$ 89° (B. **40,** 171). Similarly, glyoxal and glycol form *Glyoxal Diethylene Acetal,* $C_2H_4:O_2CH.CHO_2:C_2H_4$, m.p. 134° (B. **28,** R. 321).

Glyoxal bisulphite reacts completely with primary and secondary bases to form glycocolls or indole sulphonic acids (Vol. II.) according to the amino- base employed (B. **27,** 3238).

The action of concentrated ammonia on glyoxal results in the formation of two bases, *glycosine,*



and *Glyoxaline*



(A. **277,** 336).

The latter, which preponderates, is formed still more completely from glyoxal, two molecules of NH_3 and formaldehyde, and is the parent substance of the *glyoxalines* (*oxalines*) or *imidazoles* (*pyrro* [b] *monozoles*) (see Vol. II.). Behaviour towards *o*-phenylene diamine, comp. α-Diketones, p. 348.

Ring-forming Reactions.—Just as formaldehyde unites with hydrocyanic acid to form the nitrile of glycollic acid, and acetaldehyde the nitrile of lactic acid, so glyoxal combines to form the nitrile of tartaric acid. On the condensation of glyoxal with malonic ester and acetoacetic ester, see B. **21**, R. 636.

Glyoxime (see p. 354), **Glyoxal Osazone** (see p. 356). Urea combines with glyoxal to form *glycoluril* (*q.v.*), a diureïde.

Acetaldehyde Disulphonic Acid, $CHO.CH(SO_3H)_2$, can be considered as being a derivative of glyoxal. It is prepared (1) in the form of its bisulphite compound, when chloral is warmed with potassium sulphite; (2) by the saturation of fuming sulphuric acid with acetylene (comp. pp. 87, 210); (3) by the action of fuming sulphuric acid on acetaldehyde (C. 1902, I. 405). By warming with alkalis it passes straight into the salts of formic and methionic acids (A. **303**, 114). The *dialkylamides* of acetaldehyde disulphonic acid are obtained from sodium methionic dialkylamides and formic ester:

$$HCOOCH_3+NaCH(SO_2NR_2)_2 \longrightarrow HCO.CH(SO_2NR_2)_2 \text{ or } HOCH{:}C(SO_2NR_2)_2,$$

which, on account of its acid character probably contains the *hydroxymethylene* group (comp. p. 343; communicated by *G. Schroeter*). Further derivatives of glyoxal are those which result from the action of $2HClO$, $2HBrO$, and $2Br_2$ on acetylene—*dichloracetaldehyde*, $CHCl_2CHO$, *dibromacetaldehyde*, $CHBr_2CHO$ (comp. p. 203), *acetylene tetrabromide*, $CHBr_2.CHBr_2$ (p. 96).

Malonic Dialdehyde, $CH_2(CHO)_2$, has not yet been isolated. If β-hydroxypropionic acetal (p. 338) is oxidized with ozone, an aqueous solution is obtained which appears to contain an aldehyde. *Ethoxymethylene Acetal, β-Ethoxyacroleïn acetal,* $C_2H_5OCH : CH.CH(OC_2H_5)_2$, is prepared from propiolic aldehyde (p. 216) by heating it with alcoholic sodium alcoholate; from acroleïn dibromide (p. 215) by heating it with alcohol and then with alcoholic potassium hydroxide. Its solution in water possesses an acid reaction and reddens ferric chloride solution, since it has been converted into malonic dialdehyde, or its desmotrope *β-hydroxyacroleïn* (comp. Hydroxymethylene Ketone, p. 343).

$$HOC.CH_2CHO \text{ or } HOCH : CH.CHO.$$

Similarly, propiolic aldehyde heated with aniline hydrochloride yields *β-aniline-acroleïn anil,* $C_6H_5NHCH : CH.CH : NC_6H_5$, m.p. 115° (B. **36**, 3658, **3668**). *Propane Tetraethyl Sulphone,* $CH_2[CH(SO_2C_2H_5)_2]_2$, m.p. 154°, is derivable from malonic dialdehyde, and is synthetically prepared by the condensation of formaldehyde with two molecules of methylene diethyl sulphone (p. 209) (B. **33**, 1123).

Succinic Dialdehyde [Butane-dial], $CHO.CH_2.CH_2.CHO$, b.p.$_{10}$ 67°, can be obtained from diallyl (p. 90) by means of ozone; but is most conveniently prepared by breaking down its dioxime (p. 355), obtained from pyrrole, by N_2O_3. It is isomeric with butyrolactone (p. 374), and is also looked on as being the hydrate of furfurane, from which it can be obtained by the action of HCl in methyl alcohol, in the form of its *tetramethyl acetal,* $CH(OCH_3)_2CH_2CH(OCH_3)_2$, b.p. 202°. The *tetraethyl acetal,* b.p.$_{20}$ 116°, results from the electrolysis of the sodium salt of β-diethoxypropionic acid $(C_2H_5O)_2CHCH_2COOK$ (B. **39**, 891). Succinic dialdehyde polymerizes readily to a glassy substance from which it is regenerated on distillation (*Harries*, B. **35**, 1183; **39**, 3670). When heated with water it forms furfurane, with ammonia pyrrole, and with P_2S_3 thiophene (comp. 1,4-Diketones, p. 351).

Dibromosuccinic Aldehyde, $HCO.CHBr.CHBr.CHO$, m.p. 73°, is prepared from the aldehyde and bromine.

Bromofumaraldehyde, $HCO.CH{:}CBrCHO$, b.p.$_{15}$ 130°, is obtained by distillation of the previous compound.

On the breaking down of furfurane into *Nitrosuccinaldehyde,* and the conversion of the latter, by boiling with water, into *Fumaric Dialdehyde,* $CHO.CH : CH.CHO$, see C. 1902, I. 1272. *Dibromomaleïc Dialdehyde,* $CHO.CBr : CBrCHO$, m.p. 69°, is obtained from βγ-dibromopyroracemic acid and bromine water (A. **232**, 89).

Glutaric Dialdehyde, $HCOCH_2CH_2CH_2CHO$, is not yet known. Of its derivatives, *Glutaconic Dialdehyde,* $HCO.CH : CH.CH_2.CHO$ is obtained during the decomposition of *pyridine* (Vol. II.); and an *α-Chloroglutaconic Dialdehyde,* $HCO.CCl : CH.CH_2.CHO$, results when *phenol* (Vol. II.) is decomposed. The latter gives rise to β-chloropyridine with ammonia, and α-thiophene aldehyde with H_2S (B. **38**, 1650).

Adipic Dialdehyde [Hexane-dial], $CHO.[CH_2]_4CHO$, b.p.$_9$ 93°, is obtained from α,α$_1$-dihydroxysuberic acid by oxidation with PbO_2. Its *Tetraethyl Acetal*, $(C_2H_5O)_2CH[CH_2]_4CH(OC_2H_5)_2$, b.p.$_{10}$ 148°, results from the electrolysis of the potassium salt of γ-diethoxybutyric acid. The aldehyde polymerizes more slowly than the higher and lower homologues, although heating with water condenses it rapidly to *cyclopentene aldehyde* (Vol. II.) (B. **39**, 891).

Suberic Dialdehyde [Octane-dial], $CHO[CH_2]_6CHO$, b.p.$_{30}$ 142°, is prepared from dihydroxyadipic acid and PbO_2. It polymerizes very easily (B. **31**, 2106).

The oximes, hydrazones and osazones of the dialdehydes are described together with the corresponding compounds of the aldehyde-ketones and diketones (p. 353).

5. KETONE-ALDEHYDES OR ALDEHYDE-KETONES

α-Ketone-aldehydes.

Pyroracemic Aldehyde, *Acetyl Formyl, Methyl Glyoxal* [Propanalone], $CH_3CO.CHO$, results from the breaking down of mesityl oxide, $CH_3.CO.CH:C(CH_3)_2$, by means of ozone. Dilute acids precipitate it from its oxime, isonitroso-acetone (p. 354). It is a yellow volatile oil, which polymerizes readily.

Methyl Glyoxal Acetal, $CH_3COCH(OC_2H_5)_2$, b.p.$_{10}$ 30° (B. **38**, 1630).

Derivatives include *Dichloracetone*, $CH_3COCHCl_2$, b.p. 120° (comp. p. 224), produced from allylene and 2HClO. *Dibromacetone*, $CH_3COCHBr_2$, b.p. 142°, results from allylene and 2HBrO. Similarly, *Dichloropinacoline*, $(CH_3)_3C.CO.CHCl_2$, m.p. 51°, and *Dibromopinacoline*, $(CH_3)_3C.COCHBr_2$, m.p. 75°, are obtained from tert.-butyl acetylene. Derivatives of tert.-*Butyl Glyoxal* (C. 1900, II. 29).

Propanal Disulphonic Acid, $CH_3C(SO_3H)_2CHO$, is prepared from propionic aldehyde and fuming sulphuric acid (C. 1902, I. 405). It corresponds with acetaldehyde disulphonic acid.

Isobutyric Formaldehyde, *Isopropyl glyoxal* [3-Methyl-butanal-2-one], $(CH_3)_2CH.COCHO$, m.p. 95°, is produced from dimethyl butanonal acid by fusion or by boiling with water (B. **30**, 861).

β-Ketone Aldehydes, such as formyl acetone, $CH_3.COCH_2CHO$, have already been described (p. 343), since in the free state they assume the *aci-* configuration, which leads to their inclusion with the *β-Hydroxymethylene Ketones* or *Olefine Ketols.*

γ-Ketone Aldehydes.

Lævulinic Aldehyde [Pentanal-4-one], $CH_3.CO.CH_2.CH_2CHO$, b.p.$_{760}$ 187°, b.p.$_{12}$ 70°, is obtained from its *methylal,* b.p.$_{13}$ 86°, the reaction product of a boiling solution of hydrochloric acid in methyl alcohol on α-methyl furfural or sylvan (B. **31**, 37).

6. DIKETONES

The relative position of the CO-groups determines them to be either α- or 1,2-diketones, β- or 1,3-diketones, γ- or 1,4-diketones, etc.

They have been regarded as diketo-substitution products of the paraffins, hence the name. The "Geneva names" contain the syllable "di" between the paraffin name and the ending "one"; thus [Butane-dione] for $CH_3.CO.COCH_3$. The α-diketones are most generally designated as compounds of two acid radicals, *e.g. diacetyl* for $CH_3CO.COCH_3$; the β-diketones as monoketones containing acid radicals, *e.g. acetyl acetone*, $CH_3CO.CH_2.CO.CH_3$.

The diketones react like the monoketones with hydroxylamine and phenylhydrazine. Their oximes, prepared in another manner, constitute the chief raw material from which to prepare the α-diketones. The nitrogen-containing derivatives of the diketones, the aldehyde ketones and dialdehydes will be discussed after the diketones, because of their greater significance in this position.

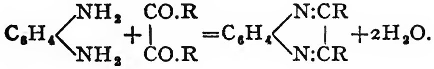
For the mercaptol and sulphone formation of the diketones, see B. **35**, 493.

(1) **α- or 1,2-Diketones.**

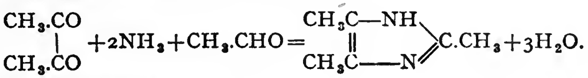
These are obtained (1) from their monoximes, the isonitroso-ketones, by boiling the latter with dilute sulphuric acid (v. *Pechmann*) (B. **20**, 3213; **21**, 1411; **22**, 527, 532; **24**, 3954; C. 1904, II. 1701); (see *pyroracemic aldehyde*). They are also formed (2) by the oxidation of the α-ketoles, *e.g.* the synthetic acyloïns (p. 341); and (3) accompanied by dinitro-paraffins (p. 154), when monoketones or the corresponding secondary alcohols are oxidized by nitric acid (B. **28,** 555; C. 1900, II. 624; 1901, II. 334); (4) from α-bromolefine ketones containing the group —C : CBrCO—, instead of the expected α-olefine ketone-alcohols (p. 343), (B. **34,** 2092).

The α-diketones, in contradistinction to the colourless aliphatic monoketones, are yellow, volatile liquids with a penetrating quinone-like odour; comp. glyoxal (p. 346). On the absorption spectra of α-diketones, see C. 1906, II. 495.

(1) The α-diketones are characterized and distinguished from the β- and γ-ketones by their ability to unite with the orthophenylene diamines (similarly to glyoxal). In this way they are condensed to the *quinoxalines* (*q.v.*):

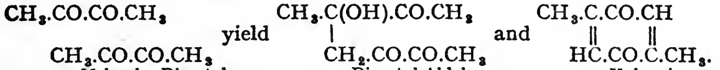


All compounds containing the group —CO.CO—, *e.g.* glyoxal, pyroracemic acid, glyoxylic acid, alloxan, dihydroxytartaric acid, etc., react similarly with the *o*-phenylenediamines. (2) The *glyoxalines* are the products of the union of the α-diketones with ammonia and the aldehydes:



(3) *Nucleus-synthetic reactions:*

α-Diketones, containing a CH_2-group, together with the CO-group, undergo a rather remarkable condensation when acted on by the alkalis. *Aldols* are first produced, and later the *quinones* (B. **22,** 2215; **28,** 1845):



$$\begin{array}{c} CH_3.CO.CO.CH_3 \\ CH_3.CO.CO.CH_3 \end{array} \text{ yield } \begin{array}{l} CH_3.C(OH).CO.CH_3 \\ | \\ CH_2.CO.CO.CH_3 \end{array} \text{ and } \begin{array}{l} CH_3.C.CO.CH \\ \| \qquad \| \\ HC.CO.C.CH_3. \end{array}$$

2 Molecules Diacetyl. Diacetyl Aldol. p-Xyloquinone.

(4) Diacetyl and hydrocyanic acid yield the nitrile of dimethyl racemic acid (see glyoxal) (B. **22,** R. 137).

Diacetyl, $CH_3.CO.CO.CH_3$, *Diketobutane, Dimethyl Diketone, Dimethyl Glyoxal* [Butane-dione], b.p. 87–89°, is obtained (1) from isonitroso-ethyl methyl ketone by the breaking down action of dilute sulphuric acid (B. **40,** 4337); (2) from methyl ethyl ketone or methyl ethyl carbinol by oxidation with nitric acid: it is accompanied by dinitro-ethane (p. 155); (3) from oxalic diacetic or ketipic acid, $COOH.CH_2CO.CO.CH_2COOH$, by elimination of $2CO_2$ by heat (B. **20,** 3183); (4) by oxidation of tetrinic acid (*q.v.*) by $KMnO_4$ (B. **26,** 2220; A. **288,** 27); (5) by electrolysis of pyroracemic acid, $CH_3CO.COOH$ (B. **33,** 650); (6) from vinylidene oxanilide, an oxalic acid derivative, and methyl magnesium iodide (B. **40,** 186). When shaken with hydrochloric acid, diacetyl polymerizes to the *trimeric* $(CH_3CO.COCH_3)_3$, m.p. 105°, b.p. 280°, which decomposes on prolonged heating (B. **35,** 3290; **36,** 954).

Tetrachlorodiacetyl, $CHCl_2.CO.CO.CHCl_2$, m.p. 84°, results in the action of potassium chlorate on chloranilic acid (together with tetrachloracetone, p. 224) (B. **22,** R. 809; **23,** R. 20).

Tetrabromodiacetyl, $(CHBr_2.CO)_2$ (B. **23,** 35) and *Dibromodiacetyl,* $(CH_2Br.CO)_2$, are produced by the action of bromine on diacetyl.

Acetyl Propionyl, $C_2H_5.CO.CO.CH_3$, *Methyl Ethyl Diketone* [2,3-Pentane-dione], b.p. 108°, is obtained from isonitroso-diethyl ketone; also by the hydrolysis of α-bromethylidene acetone, $CH_3CH{:}CBrCOCH_3$ (B. **34,** 2092). It condenses to duroquinone. *Acetyl Butyryl* [2,3-Hexane-dione], $C_3H_7COCOCH_3$, b.p. 128°, *Acetyl Isobutyryl,* $(CH_3)_2CHCO.COCH_3$, b.p. 115°, results from the hydrolysis of acetoxymesityl oxide (p. 343). *Acetyl Isovaleryl,* $(CH_3)_2CHCH_2\ COCOCH_3$, b.p. 138°. *Acetyl Caproyl,* $CH_3[CH_2]_4COCOCH_3$, b.p. 172° (C. 1898, II. 965; 1900, II. 624). *Acetyl Isocaproyl,* $(CH_3)_2CHCH_2CH_2COCOCH_3$, b.p. 163° (B. **22,** 2117; **211,** 3956).

Symmetrical diketones: *Dipropionyl,* $CH_3CH_2CO.COCH_2CH_3$. *Dibutyryl,* $CH_3CH_2CH_2CO.COCH_2CH_2CH_3$, b.p. 168°. *Di-isobutyryl,* $(CH_3)_2CHCO.CO\text{-}CH(CH_3)_2$, b.p. 145°. *Di-isovaleryl,* $(CH_3)_2CHCH_2CO.COCH_2CH(CH_3)_2$.

Dicaproyl, $C_5H_{11}COCOC_5H_{11}$, b.p.$_{22}$ 110–120°. *Dipivaloyl*, $(CH_3)_3C.CO.CO.C(CH_3)_3$, b.p. 170°. All these bodies are obtained from the *α*-ketols, the acyloïns (pp. 315, 341) by oxidation with nitric acid or dehydration by means of finely divided copper (J. pr. Ch.[2] **62**, 364; C. 1906, II. 1115).

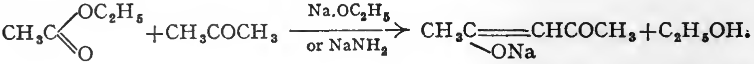
α-Diketone Dichlorides result in the action of hypochlorous acid on alkylated acetylenes (p. 89), according to the equation:

$$C_2H_5C⋮CCH_3+2HClO=C_2H_5CCl_2.COCH_3+H_2O.$$

Methyl α-Dichloropropyl Ketone, $C_2H_5.CCl_2.CO.CH_3$, b.p. 138°, yields methyl n-propyl ketone on reduction; with potassium carbonate solution it forms duroquinone, angelic acid (p. 298), and *α*-ethyl acrylic acid. The two acids result from an intramolecular atomic rearrangement which recalls that of the formation of benzilic acid from benzil (p. 38).

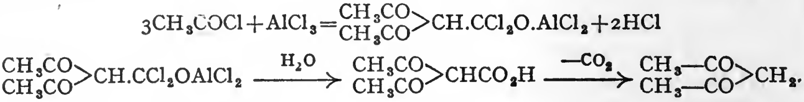
(2) *β*- or 1,3-**Diketones** are produced according to two nucleus-synthetic reactions: (1) like the hydroxymethylene ketones, by the interaction of acetic esters and ketones in the presence of sodium ethoxide, or, better, metallic sodium (*Claisen*, B. **22**, 1009; **23**, R. 40; **38**, 695).

The condensation probably proceeds similarly to that leading to the formation of hydroxymethylene ketones (p. 343) and of acetoacetic ester (p. 412); the first step consists in the action of sodium or its compounds on the ester, the second in condensation and elimination of alcohol with the formation of the sodium salt of the *aci*- form of the *β*-diketone:



$$CH_3C\begin{matrix}\diagup OC_2H_5\\ \diagdown O\end{matrix}+CH_3COCH_3\xrightarrow[\text{or }NaNH_2]{Na.OC_2H_5}CH_3C\begin{matrix}=\!=\!=CHCOCH_3\\ \diagdown ONa\end{matrix}+C_2H_5OH.$$

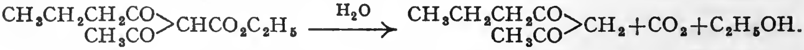
(2) By the action of $AlCl_3$ on acetyl chloride and the subsequent decomposition of the aluminium derivative. This reaction was discovered by *Combes*, but correctly interpreted by *Gustavson* (B. **21**, R. 252; **22**, 1009; C. 1901, I. 1263):



$$3CH_3COCl+AlCl_3=\begin{matrix}CH_3CO\\CH_3CO\end{matrix}\!>CH.CCl_2O.AlCl_2+2HCl$$

$$\begin{matrix}CH_3CO\\CH_3CO\end{matrix}\!>CH.CCl_2OAlCl_2\xrightarrow{H_2O}\begin{matrix}CH_3CO\\CH_3CO\end{matrix}\!>CHCO_2H\xrightarrow{-CO_2}\begin{matrix}CH_3\!-\!CO\\CH_3\!-\!CO\end{matrix}\!>CH_2.$$

(3) Acyl acetoacetic ester (p. 419), when heated with water at 140–150° decomposes into CO_2, alcohol and *β*-diketone (acyl acetone) (C. 1903, I. 225):



$$\begin{matrix}CH_3CH_2CH_2CO\\CH_3CO\end{matrix}\!>CHCO_2C_2H_5\xrightarrow{H_2O}\begin{matrix}CH_3CH_2CH_2CO\\CH_3CO\end{matrix}\!>CH_2+CO_2+C_2H_5OH.$$

Constitution.—The *β*-diketones, like the hydroxymethylene ketones (p. 343), have an acid character. Although the formyl ketones are regarded as hydroxymethylene derivatives, the disposition generally is to assign to the salts of the *β*-diketones, *e.g.* $CH_3.CO.CH=C(ONa)CH_3$, the *keto-enol* formula, retaining for the free ketones, however, the diketo formula. Comp. also *acetoacetic ester*, and *formyl acetic ester* (A. **277**, 162). The molecular refraction is an argument in favour of this view (B. **25**, 3074).

Reactions.—A very characteristic reaction is the precipitation of their alkali salts by copper acetate. Ferric chloride imparts an intense red colour to their alcoholic solution.

When the salts of *β*-diketones are treated with iodoalkyls, the CH_2-group becomes alkylated (comp. Acetoacetic Ester):

$$CH_3COCH_2COC_3H_7\xrightarrow[CH_3I]{C_2H_5ONa}CH_3COCH(CH_3)COC_3H_7.$$

Hydroxylamine converts the *β*-diketones into *isoxazoles*, phenyl-hydrazine into *pyrazoles* (pp. 354, 356).

Acetyl Acetone, $CH_3CO.CH_2.CO.CH_3$, b.p. 137° (above, for its formation). Electrolysis of an alcoholic solution of sodium acetyl acetone, or the action of iodine on the same body, leads to the formation of tetra-acetyl ethane (B. **26**, R. 884). With S_2Cl_2 and SCl_2 it forms dithio- and monothio-acetyl acetone respectively (B. **27**, R. 401, 789). H_2S produces a dimeric *Dithioacetyl Acetyl Acetone* $(C_5H_8S_2)_2$, m.p. 163 (C. 1901, II. 397). Cyanogen unites with acetyl acetone in presence of a little sodium ethoxide to form *Cyanimidomethyl Acetyl*

Acetone, NC.C(NH).CH$(COCH_3)_2$, m.p. 130°, and *Diimidotetra-acetyl Butane,* $(CH_3CO)_2C(NH)C(NH)CH(COCH_3)_2$, m.p. 147° (B. **31**, 2938).

The *metallic salts* of acetyl acetone resemble one another in their remarkable stability. Those of Be, Al, Cr, Mn, Zn, Fe, Cu, Hg, Mo, Pt″, Ce, La, Th, and others have been prepared, of which some, on account of their power of crystallization, have been employed for the determination of the valency and atomic weights of the rare elements (C. 1900, I. 588; B. **34**, 2584; A. **331**, 334). *Copper Acetyl Acetone,* $Cu(C_5H_7O_2)_2$. *Beryllium Acetyl Acetone,* $Be(C_5H_7O_2)_2$, m.p. 108°, b.p. 270°. *Aluminium Acetyl Acetone,* $Al(C_5H_7O_2)_3$, m.p. 193°, b.p. 314°. The vapour density of these compounds reveals the divalence of Br and the trivalence of Al. *Chromium Acetyl Acetone,* $Cr(C_5H_7O_2)_3$, b.p. 340°, is of a violet colour, and gives off a green vapour (*Coombes,* B. **28**, R. 10; C. 1899, II. 525).

Octochloracetyl Acetone, m.p. 53, and *Octobromacetyl Acetone,* CBr_3COCBr_2-$COCBr_3$, m.p. 154°, are obtained from phloroglucinol, and chlorine or bromine respectively (Vol. II.) (B. **23**, 1717).

Alkylated acetyl acetones are obtained from acetyl acetone by sodium and iodo-alkyls (B. **20**, R. 283; **21**, R. 11).

Acetyl Methyl Ethyl Ketone, Acetyl Propionyl Methane, $CH_3COCH_2COC_2H_5$, b.p. 158°. *Acetyl Methyl Propyl Ketone, Acetyl Butyryl Methane,* b.p. 175° (B. **22**, 1015; C. 1903, I. 225). *Acetyl Isobutyryl Methane,* b.p. 168° (B. **31**, 1342; C. 1900, II. 317). *Acetyl Caproyl Methane,* $CH_3[CH_2]_4COCH_2.COCH_3$, $b.p._{20}$ 100°, also results from acetyl œnanthylidene (p. 232) and sulphuric acid (C. 1900, II. 1262; 1903, I. 225).

Higher β-diketones: see C. 1902, I. 568.

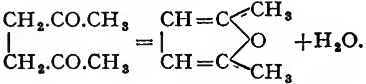
(3) γ- or 1,4-**Diketones.**

These correspond with the paraquinones of the aromatic series (*q.v.*). They are not capable of forming salts, hence are not soluble in the alkalis. They form mono- and di-oximes with hydroxylamine, and mono- and di-hydrazones with phenylhydrazine; these are colourless. The readiness with which the γ-diketones form pyrrol, furfurane, and thiophene derivatives is characteristic of them.

Acetonyl Acetone, sym.-*Diacetyl Ethane,* [2,5-Hexane-dione], CH_3-$CO.CH_2CH_2COCH_3$, m.p. −9°, b.p. 194°, $D_{20} = 0{\cdot}973$, is obtained from pyrotritaric acid, $C_7H_8O_3$ (*q.v.*); from *acetonyl acetoacetic ester* (*q.v.*), when heated to 160° with water (B. **18**, 58); and from isopyrotritaric acid and diacetyl succinic ester, when they are boiled with potassium carbonate solution (B. **33**, 1219). It is a liquid with an agreeable odour, and is miscible with water, alcohol, and ether.

Conversion of Acetonyl Acetone into 1,4-*Dimethyl Furfurane, -Thiophene,* and *-Pyrrole* (*Paal,* B. **18**, 58, 367, 2251).

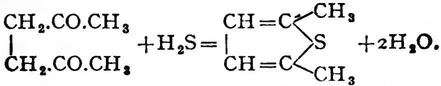
(1) The direct removal of one molecule of water from acetonyl acetone by distillation with zinc chloride or P_2O_5 results in the formation of dimethyl furfurane (B. **20**, 1085):



Dimethyl Furfurane.

Other γ-diketone compounds react in a similar manner (*Knorr,* B. **17**, 2756).

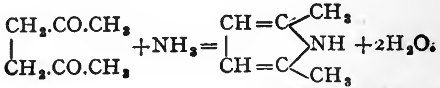
(2) When heated with phosphorus sulphide acetonyl acetone yields dimethyl thiophene:



Dimethyl Thiophene.

All the γ- diketones or 1,4-dicarboxyl compounds, *e.g.* the γ-ketonic acids (*q.v.*), yield the corresponding thiophene derivatives upon like treatment (B. **19,** 551).

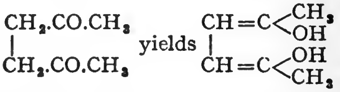
(3) *Dimethyl Pyrrole* is produced on heating acetonyl acetone with alcoholic ammonia:



Dimethyl Pyrrole.

All compounds containing two CO-groups in the 1,4-position react similarly with ammonia and amines, *e.g.* diacetosuccinic ester and lævulinic ester. All the pyrrole derivatives formed as above, when boiled with dilute mineral acids, have the power of colouring a pine chip an intense red. This reaction is, therefore, a means of recognizing all 1,4-diketone compounds (B. **19,** 46).

In all these conversions of acetonyl acetone into pyrrole, thiophene, and furfurane derivatives, it may be assumed that it first passes from the diketone form into the pseudo-form of the diolefine glycol (p. 38):



$$\begin{matrix} CH_2.CO.CH_3 \\ | \\ CH_2.CO.CH_3 \end{matrix} \text{ yields } \begin{matrix} CH{=}C{<}^{CH_3}_{OH} \\ | \\ CH{=}C{<}^{OH}_{CH_3} \end{matrix}$$

and from this, by replacing the 2OH-groups with S, O, or NH, the corresponding *furfurane, thiophene,* and *pyrrole* compounds are produced (B. **19,** 551).

ω-Dimethyl Lævulinic Methyl Ketone, *α-Dimethyl Acetonyl Acetone,* $(CH_3)_2CH.CO.CH_2CH_2COCH_3$, b.p.$_{12}$ 91°, is a degradation product of tanacetone, a terpene ketone (Vol. II.). It is prepared from methyl heptenone glycol, $(CH_3)_2C(OH).CH(OH).CH_2CH_2.COCH_3$, by boiling with sulphuric acid (B. **35,** 1179).

1,5- or **δ-Diketones** are not known. If it is attempted to prepare them from the δ-diketone dicarboxylic esters, *e.g.* *αα*-diacetyl glutaric ester:

$$\begin{matrix} CH_3CO \\ C_2H_5OCO \end{matrix}{>}CHCH_2CH{<}\begin{matrix} COCH_3 \\ COOC_2H_5 \end{matrix}$$

(resulting from the condensation of aldehydes and acetoacetic esters) by splitting off carboxyethyl groups, there results instead of, for example, diacetyl propane or 2,5-heptane-dione, $CH_3CO.CH_2CH_2CH_2.COCH_3$, a carbocyclic condensation product—3-Methyl-Δ_2-R-hexene (A. **288,** 321).

1,6- or **ε-Diketones.** *Diacetyl Butane* [2,7-Octane-dione], m.p. 44°, results from the electrolysis of potassium lævulinate:

$$2CH_3COCH_2CH_2 \vdots COO \vdots K \longrightarrow CH_3COCH_2CH_2.CH_2CH_2.COCH_3.$$

It is also obtained by the ketonic decomposition of diacetyl adipic ester (*q.v.*) (B. **33,** 650).

1,7- or **ζ-Diketone,** *Diacetyl Pentane,* $CH_3CO.(CH_2)_5.COCH_3$, belongs to this class. When reduced, it undergoes an intramolecular pinacone formation and becomes *Dimethyl Dihydroxyheptamethylene,* $CH_3.\overline{C(OH)[CH_2]_5C}(OH)CH_3$ (B. **23,** R. 249; **24,** R. 634; **26,** R. 316).

NITROGEN-CONTAINING DERIVATIVES OF THE DIALDEHYDES, ALDEHYDE KETONES AND DIKETONES

1. For the action of ammonia on glyoxal and acetonyl acetone, consult pp. 346, 352.

2. **Oximes.**

A. **Monoximes.**—(*a*) *Aldoximes of the* α*-aldehyde ketones and monoximes of the* α*-diketones: isonitrosoketones or oximido-ketones.* These bodies are formed (1*a*) by the action of nitrogen trioxide on ketones (B. **20,** 639). By this reaction mixed ketones, which contain the —CO— group united to two CH_2-groups, yield two different isonitroso-ketones; but if the —CO— group is joined to a tertiary alkyl, only one isonitroso-ketone is formed (C. 1898, II. 965).

(1*b*) When amyl nitrite in the presence of sodium ethoxide or hydrochloric acid acts on ketones. Sometimes one and sometimes the other reagent gives the best yield (B. **20,** 2194; **28,** 1915):

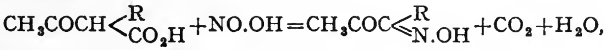
$$CH_3COCH_3+NO.O.C_5H_{11}=CH_3COCH(N.OH)+C_5H_{11}.OH.$$

An excess of amyl nitrite decomposes the oximido-body, whereby the oximido-group is replaced by oxygen, with the production of *a*-diketo-derivatives (B. **22,** 527; C. 1904, II. 1701).

(2) Just as acetone is formed from acetoacetic ester, so can isonitroso- or oximido-acetone be prepared from the oximido-derivative of acetoacetic ester (B. **15,** 1326). Nitrous acid decomposes acetoacetic acid into oximido-acetone and carbon dioxide:

$$CH_3COCH_2CO_2H+NO.OH=CH_3.COCH(N.OH)+CO_2+H_2O.$$

Similarly, by the action of nitrous acid, nitrosyl sulphate or chloride, the oximido-compounds of the higher acetones can be directly derived from the monoalkylic acetoacetic acids and their esters by elimination of carbon dioxide (B. **20,** 531; C. 1904, II. 1700):



$$CH_3COCH\begin{cases}R\\CO_2H\end{cases}+NO.OH=CH_3COC\begin{cases}R\\N.OH\end{cases}+CO_2+H_2O,$$

whilst the dialkylic acetoacetic acids do not react (B. **15,** 3067).

Properties.—The isonitroso- or oximido-ketones are colourless, crystalline bodies, easily soluble in alcohol, ether and chloroform, but usually more sparingly soluble in water. They dissolve in the alkalis, the hydrogen of the hydroxyl group being replaced by metal, with the formation of salts having an intensely yellow colour. They yield a yellow coloration with phenol and sulphuric acid, and not the blue coloration of the nitroso-reaction (B. **15,** 1529).

Reactions.—(1) As in the ketone-oximes, so also in the isonitroso-ketones, the oximido-group can be split off and be replaced by oxygen, which will lead to the formation of diketo-bodies, —CO.CO—. This result may be brought about by the addition of sodium bisulphite and boiling the resulting imidosulphonic acid with dilute acids (B. **20,** 3162). The reaction also takes place when isonitrosoketones are boiled directly with dilute sulphuric acid (B. **20,** 3213). The decomposition is sometimes more readily effected by nitrous acid (B. **22,** 532; C. 1904, II. 1701).

(2) The aldoximido-ketones, like the aldoximes (p. 212), are converted by dehydrating agents—*e.g.* acetic anhydride—into acidyl cyanides or α-ketone carboxylic nitriles (*q.v.*) (B. **20,** 2196).

(3) *Aminoketones* (p. 344) are produced in the reduction of isonitroso-ketones by means of stannous chloride.

(4) Two molecules of phenylhydrazine, acting on the isonitroso-ketones, produce *osazones, e.g.* $CH_3.C(N_2H.C_6H_5)CH(N_2H.C_6H_5)$—acetonosazone (B. **22,** 528). Semicarbazide gives rise to *semicarbazone oximes*, most of which are slightly soluble and possessed of high melting points (C. 1904, II. 304, 1700).

(5) By the further action of hydroxylamine or its hydrochloride (B. **16,** 182; C. 1904, II. 1700) on isonitroso-acetone, the ketone oxygen is replaced and *dioximes* of the α-aldehyde ketones and α-diketones are produced.

(6) Halogen alkyls acting on the salts of isonitroso-ketones produce *ethers* (comp. B. **15,** 3073; **38,** 1917):

$$CH_3CO.C(NOK)CH_3+CH_3I=CH_3CO.C(NOCH_3).CH_3+KI.$$

which are the *alkoximes* of the α-diketones. They are more stable than the free isonitroso-ketones, and are therefore more suitable for use in many synthetic reactions.

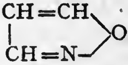
Isonitroso-acetone, *Aldoxime of Pyroracemic Aldehyde,* $CH_3.CO.$-$CH:(N.OH)$, m.p. 65°, is very readily soluble in water ; crystallizes in silvery, glistening tablets or prisms ; melts and decomposes at higher temperatures, but may be volatilized in a current of steam.

Monoximes of the α-Diketones.—*Isonitroso-ethyl Methyl Ketone,* $CH_3CO.C{=}NOH.CH_3$, m.p. 74°, b.p. 185–188°. Preparation (B. **35**, 3290). Action of HCl on isonitroso-ethyl methyl ketone (B. **38**, 3357). *Isonitroso-methyl Propyl Ketone,* $CH_3CO.C{=}NOH.CH_2CH_3$, m.p. 52–53°, b.p. 183–187°. *Isonitroso-diethyl Ketone,* $C_2H_5.COC{=}NOH.CH_3$, m.p. 59–62°. *Isonitroso-methyl Butyl Ketone,* $CH_3.COC{=}NOH.C_3H_7$, m.p. 49·5°. *Isonitroso-methyl Isobutyl Ketone,* $CH_3.COC{=}NOH.CH(CH_3)_2$, m.p. 75°. *Isonitroso-methyl Isoamyl Ketone,* $CH_3.$-$COC{=}NOH.CH_2.CH(CH_3)_2$, m.p. 42° C. *Isonitroso-methyl Isocapryl Ketone,* $CH_3.COC{=}NOH.CH_2CH_2CH(CH_3)_2$, m.p. 38°.

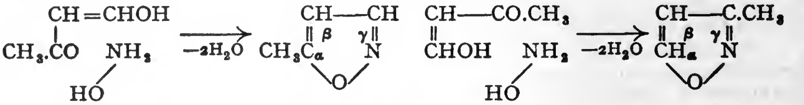
For other isonitroso-ketones see C. 1899, I. 190 ; II. 524 ; 1904, II. 1700.

B. **Oxime-anhydrides of the β-Diketones or Isoxazoles.**

Monoximes of the β-formyl ketones and of the β-diketones are not known. In the attempt to prepare them water is lost and an intramolecular anhydride formation takes place. The oxime-anhydrides are isomeric with the oxazoles, which also consist of five members ; hence their name, *isoxazoles* (B. **21**, 2178 ; **24**, 390 ; **25**, 1787).

Isoxazole, *Oxime-anhydride of Malonic Dialdehyde,*  , b.p. 95°, is prepared from propargyl aldehyde or β-anilino-acroleïn anil (p. 347) by hydroxylamine. Alcoholic alkalis convert it into cyanacetaldehyde (p. 401) (B. **36**, 3665) :

α-Methyl Isoxazole, CH_3-α-C_3H_2NO, b.p. 122°, and *γ-Methyl Isoxazole,* CH_3-γ-C_3H_2NO, b.p. 118°, result from hydroxymethylene or formyl acetone. They are transparent liquids, having an intense odour resembling that of pyridine. α-Methyl isoxazole readily becomes rearranged into cyanacetone (*q.v.*) :



αγ-Dimethyl Isoxazole $(CH_3)_2$-αγ-C_3HNO, b.p. 141°, has a very peculiar odour, and is obtained from acetyl acetone and hydroxylamine hydrochloride.

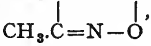
C. **Dioximes.**

(*a*) **Glyoximes or α-Dioximes.**—When glyoxal, of which the monoxime is not known, pyroracemic aldehyde and the α-diketones are treated with hydroxylamine hydrochloride, the α-dioximes or glyoximes are formed. They can also be obtained from α-isonitroso-ketones or α-dichloroketones. The glyoximes form characteristic complex compounds with Ni, Co, Pt, Fe, Cu, which are stable and strongly coloured ; the metal is united to two glyoxime molecules (B. **39**, 2692, 3382).

Glyoxime, $CH({=}NOH).CH({=}NOH)$, m.p. 178° (B. **17**, 2001 ; **25**, 705 ; **28**, R. 620), is prepared from trichlorolactic acid (p. 368). *Methyl Glyoxime, Acetoximic Acid,* $CH_3C(NOH).CH(NOH)$, m.p. 153°. **Dimethyl Glyoxime,** *Diacetyldioxime,* $CH_3C(NOH).C(NOH)CH_3$, m.p. 234° (B. **28**, R. 1006 ; J. pr. Ch. [2] **77**, 414) is employed as a sensitive test for the presence of Ni.(Tr). *Methyl Ethyl Glyoxime,* $CH_3C(NOH).C(NOH).C_2H_5$, m.p. 172° ((B. **34**, 3978). *Methyl Propyl Glyoxime,* m.p. 168°. tert.-*Butyl Glyoxime,* $(CH_3)_3C.C(NOH)$-$CH(NOH)$, m.p. 102°, is prepared from dichloropinacoline (p. 348). *Methyl*

Isobutyl Glyoxime, m.p. 170–172°. Higher homologues of glyoxime, see C. 1899, II. 524; 1904, II. 1700.

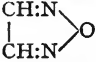
(*b*) **Glyoxime Peroxides** (B. **23**, 3496) result when NO_2 acts on an ethereal solution of the glyoximes: *Dimethyl Glyoxime Peroxide*,



$$\begin{array}{l}CH_3.C{=}N{-}O\\ \quad\ \ |\qquad\quad\ \ |\\ CH_3.C{=}N{-}O\end{array}$$

, b.p. 222°. *Methyl Ethyl Glyoxime Peroxide*, b.p.$_{16}$ 115°.

(*c*) **Furazanes**, *Azoxazoles*, *Furo*-[aa$_1$]-*diazoles* are the anhydrides obtained from certain α-dioximes. *Furazane*,



$$\left.\begin{array}{l}CH{:}N\\ |\\ CH{:}N\end{array}\right>O$$

, itself is not known, whilst *dimethyl furazane*, for example, has been prepared from diacetyl dioxime.

(*d*) **β-Dioximes**, *Acetyl Acetone Dioxime*, $CH_3C(NOH)CH_2C(NOH)CH_3$, m.p. 150°, is produced from acetyl acetone by an *excess* of hydroxylamine. It easily gives this up and is converted into dimethyl isoxazole (see above). Reduction by sodium and alcohol gives 1,4-diaminopentane (p. 333). Electrolytic reduction in sulphuric acid solution leads to the formation of *Dimethyl Pyrazolidine*,

$$CH_3CH(\overline{NH)CH_2CH(N}H)CH_3$$

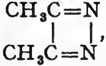
, a compound in which the nitrogen atoms have become united (B. **36**, 219).

(*e*) **γ-Dioximes**, which may be systematically derived from the γ-dialdehydes; γ-aldehyde-ketones and γ-diketones may be prepared (1) by the action of hydroxylamine on pyrrole (B. **22**, 1968) and alkyl pyrroles (B. **23**, 1788); (2) from γ-diketones and hydroxylamine. They are decomposed by boiling alkalis into the corresponding acids, or γ-diketones; the latter are far better obtained by means of nitrous acid.

Succinaldehyde Dioxime, $HON:CHCH_2CH_2CH:NOH$, m.p. 173°, passes upon reduction into tetramethylene diamine (p. 333), and into succinic dialdehyde by the action of N_2O_3 (B. **35**, 1184). *Ethyl Succinaldioxime*, $HON:CHCH(C_2H_5)$-$CH_2CH:N(OH)$, m.p. 135°.; *Propionyl Propionaldioxime*, $CH_3CH_2C:N(OH)$-$CH_2CH_2CH:N(OH)$, m.p. 85°. *Methyl Lævulinaldioxime*, $CH_3C:N(OH)CH_2$-$CH(CH)_3CH:N(OH)$. *Acetonyl Acetone Dioxime*, $CH_3C:N(OH)CH_2CH_2C:$-$N(OH)CH_3$, m.p. 135°. *ωω-Diacetyl Pentane Dioxime*, $CH_3C:N(OH)[CH_2]_5C:$-$N(OH)CH_3$, m.p. 172°.

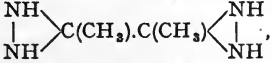
3. Hydrazine and Phenylhydrazine Derivatives.

Dimethyl Aziethane,



$$\begin{array}{l}CH_3C{=}N\\ \qquad\ |\quad\ \ |\\ CH_3C{=}N\end{array}$$

, m.p. above 270°, and *Dimethyl bishydrazimethylene*,

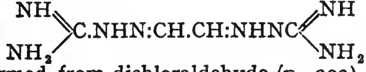


$$\left.\begin{array}{l}NH\\ |\\ NH\end{array}\right>C(CH_3).C(CH_3)\left<\begin{array}{l}NH\\ |\\ NH\end{array}\right.$$

, m.p. 158°, are obtained from diacetyl and hydrazine (J. pr. Ch. [2] **44**, 174). Dimethyl aziethane is also prepared from *Diacetyl Acetylhydrazone*, $CH_3C(N:N.COCH_3):C(OH)CH_3$, m.p. 167° by heating it with alkalis. The *mono-semicarbazones* of the α-diketones dissolve in alkalis, like the monoximes (p. 354), to a *yellow* solution. *Diacetyl Semicarbazone*, $CH_3COC(NNHCONH_2)CH_3$, or $CH_2:C(OH).C(NNHCONH_2)CH_3$, m.p. 235°. *Acetyl Propionyl Semicarbazone*, m.p. 209° (B. **36**, 3183°).

Glyoxal Disemicarbazone $(NH_2CONHN:CH—)_2$, is a slightly soluble crystalline powder of high melting point (B. **40**, 71).

Glyoxal Bisguanidine,



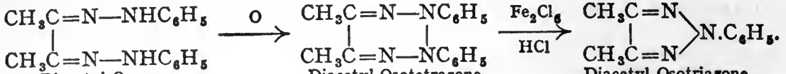
$$\left.\begin{array}{l}NH\\ NH_2\end{array}\right>C.NHN{:}CH.CH{:}NHNC\left<\begin{array}{l}NH\\ NH_2\end{array}\right.$$

$+H_2O$, m.p. 265, with decomposition, is formed from dichloraldehyde (p. 203) and amidoguanidine (A. **202**, 284). *Diacetyl Semicarbazone*, m.p. 279°.

Monophenylhydrazones.—*Hydrazone of Pyroracemic Aldehyde*, $CH_3CO.CH:$-$N.NH.C_6H_5$, m.p. 148°, is obtained by hydrolyzing the reaction-product resulting from diazobenzene chloride and sodium acetoacetic ester with alcoholic sodium hydroxide (C. 1901, I. 299). *Diacetylhydrazone*, $CH_3CO.C:(NNHC_6H_5)CH_3$, m.p. 133°, has been prepared from diacetyl- and methyl-acetoacetic ester (*Japp* and *Klingemann*) (A. **247**, 190).

α-Acetyl Propionyl Hydrazone, $CH_3C(:NNHC_6H_5).COCH_3$, m.p. 97°, is obtained from acetyl propionyl. *β-Acetyl Propionyl Hydrazone*, $CH_3CO.C:(NNHC_6H_5)CH_3$, m.p. 117°, is prepared from ethyl acetoacetic acid and diazobenzene chloride.

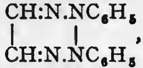
Diphenylhydrazones or **Osazones.**—Glyoxal (p. 346), methyl glyoxal (p. 348), the α-diketones and the α-isonitroso-acetones, when treated with phenylhydrazine, lose two molecules of water or water and hydroxylamine, respectively, and form diphenylhydrazones or **osazones,** which can also be obtained from α-hydroxyaldehydes, α-hydroxyketones, α-aminoaldehydes and α-aminoketones. The osazones have become especially important for the chemistry of the aldopentoses, and the aldo- and ketohexoses. The osazones are oxidized by potassium chromate and acetic acid to *osotetrazones,* which are converted by hydrochloric acid and ferric chloride into *osotriazones :*



$$\begin{array}{l} CH_3C=N-NHC_6H_5 \\ \quad | \\ CH_3C=N-NHC_6H_5 \end{array} \xrightarrow{O} \begin{array}{l} CH_3C=N-NC_6H_5 \\ \quad |\qquad\quad\ | \\ CH_3C=N-NC_6H_5 \end{array} \xrightarrow[HCl]{Fe_2Cl_6} \begin{array}{l} CH_3C=N \\ \quad | \qquad\quad \rangle N.C_6H_5. \\ CH_3C=N \end{array}$$

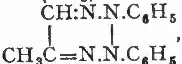
Diacetyl Osazone. Diacetyl Osotetrazone. Diacetyl Osotriazone.

Glyoxal Osazone, $C_6H_5NH.N:CHCH:N.NHC_6H_5$, m.p. 177°, is also prepared from formaldehyde and phenylhydrazine, with the intermediate formation of glycolyl aldehyde (p. 337) (B. **30,** 2459). *Glyoxal Osotetrazone,*



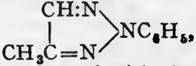
$$\begin{array}{l} CH:N.NC_6H_5 \\ | \qquad\quad | \\ CH:N.NC_6H_5 \end{array},$$

m.p. 145° (B. **17,** 2001 ; **21,** 2752 ; **26,** 1045). *Methyl Glyoxal Osazone,* $C_6H_5NH.N:C(CH_3)CH:N.NHC_6H_5$, m.p. 145° (B. **26,** 2203). *Methyl Glyoxal Osotetrazone,*



$$\begin{array}{l} CH:N.N.C_6H_5 \\ | \qquad\quad | \\ CH_3C=N.N.C_6H_5 \end{array},$$

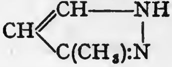
m.p. 107°. *Methyl Glyoxal Osotriazone,*



$$\begin{array}{l} CH:N \\ | \qquad\ \rangle NC_6H_5, \\ CH_3C=N \end{array}$$

b.p.$_{10}$ 150° (B. **21,** 2755). *Diacetyl Osazone* (formula above), m.p. 236° with decomposition (B. **20,** 3184 ; A. **249,** 203). *Diacetyl Osotetrazone* (formula above), m.p. 169° with decomposition. *Diacetyl Osotriazone* (formula above), m.p. 35°, b.p. 255° (B. **21,** 2759). *Acetyl Propionyl Osazone,* m.p. 162° (B. **21,** 1414 ; A. **247,** 221).

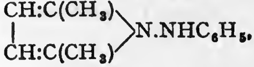
The 1,3-diketones and the 1,3-hydroxymethylene ketones (p. 343) unite with hydrazine and phenylhydrazine, forming **pyrazoles** (Vol. II.), which may be regarded as derivatives of the 1,3-olefine ketols (A. **279,** 237) : *e.g.* hydroxymethylene acetone and hydrazine yield 3-**Methyl Pyrazole,**



$$CH\begin{array}{l} \diagup CH — NH \\ \qquad\qquad\ \ | \\ \diagdown C(CH_3):N \end{array}$$

(B. **27,** 954).

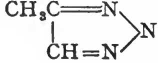
Acetonyl acetone, a 1,4-diketone, and phenylhydrazine yield : *Acetonyl Acetonosazone,* m.p. 120°, and *Phenylamido-Dimethyl-Pyrrole,*



$$\begin{array}{l} CH:C(CH_3) \\ | \qquad\qquad\ \rangle N.NHC_6H_5, \\ CH:C(CH_3) \end{array}$$

m.p. 90°, b.p. 270° (B. **18,** 60 ; **22,** 170).

α-**Hydrazoximes.**—*Methyl Glyoxal Phenylhydrazoxime,* $CH_3.C:N(NHC_6H_5).CH:NOH$, m.p. 134°, is prepared by the action of phenylhydrazine on isonitroso-acetoacetic acid. It parts readily with water and becomes methyl n-phenyl osotriazole,



$$\begin{array}{l} CH_3C=N \\ | \qquad\quad \rangle NC_6H_5 ; \\ CH=N \end{array}$$

(Vol. II.) (A. **262,** 278).

7. ALCOHOL- or HYDROXY-ACIDS, $C_nH_{2n}\begin{matrix}\diagup CO_2H\\ \diagdown OH\end{matrix}$

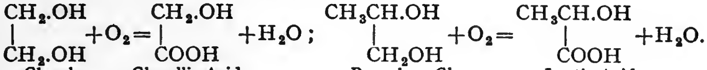
Acids of this series show a twofold character in their entire behaviour. Since they contain a carboxyl group, they are *monobasic acids* with all the attaching properties and reactions of the latter ; the OH-group linked to the radical bestows upon them all the properties of the *monohydric alcohols.* As already indicated in the introduction to the dihydric compounds, these alcohols must be distinguished as primary, secondary, and tertiary, according as they contain, in addition to the carboxyl group, the group $—CH_2OH$, characteristic of primary alcohols, the radical$=CHOH$, peculiar to the secondary alcohols, or the tertiary alcohol group $\equiv C.OH$. This difference manifests itself in the behaviour of these bodies when subjected to oxidation.

However, the manner in which the alcoholic hydroxyl group in an alcohol-acid acts on the carboxyl group present in the same molecule depends greatly on the position of these two groups with reference to each other. It is just this differentiating, opposing position of the two reactive groups which induces class differences of a distinctly new type, which are therefore made prominent because the oxidations undergone by primary, secondary and tertiary alcohols are already known to us. At present they are mostly termed *hydroxy-fatty acids*, because of their origin from the fatty acids by the replacement of a hydrogen atom by OH.

The "Geneva names" are formed by the insertion of the syllable "ol," characteristic of alcohols, between the name of the hydrocarbon and the word "acid"; $CH_2OH.COOH$, hydroxyacetic acid, or [*ethanol acid*].

Glycollic and *ordinary* or *lactic acid of fermentation* are the best-known and most important representatives.

General Methods of Formation.—(1) Careful oxidation (*a*) of di-primary, primary-secondary and primary-tertiary glycols with dilute nitric acid, or platinum sponge and air:



$$\begin{array}{c}CH_2.OH\\ |\\ CH_2.OH\end{array} + O_2 = \begin{array}{c}CH_2.OH\\ |\\ COOH\end{array} + H_2O; \quad \begin{array}{c}CH_3CH.OH\\ |\\ CH_2OH\end{array} + O_2 = \begin{array}{c}CH_3CH.OH\\ |\\ COOH\end{array} + H_2O.$$

Glycol. Glycollic Acid. α-Propylene Glyco α-Lactic Acid.

(*b*) By the oxidation of hydroxyaldehydes.

(2) The action of nascent hydrogen (sodium amalgam, zinc and hydrochloric or sulphuric acid, sodium and alcohol, or electrolysis) on the *aldehyde acids*, the *ketonic acids*, and *dicarboxylic acids*.

Pyroracemic Acid, $CH_3.CO.CO_2H + 2H = CH_3.CH(OH).CO_2H$.
Oxalic Acid, $COOH.COOH + 4H = COOH.CH_2OH + H_2O$.

This reaction has been repeatedly used in preparing β-, γ- and δ-hydroxy-acids from β-, γ- and δ-ketone carboxylic esters.

(3) Some fatty acids have OH directly introduced into them. This is accomplished by oxidizing them with $KMnO_4$ in alkaline solution.

Only acids containing the tertiary group CH (a so-called tertiary H-atom) are adapted to this kind of reaction (*R. Meyer*, B. **11**, 1283, 1787; **12**, 2238; A. **208**, 60; **220**, 56). Nitric acid effects the same as $KMnO_4$ (B. **14**, 1782; **16**, 2318).

(4) By heating unsaturated fatty acids with aqueous potassium or sodium hydroxide to 100° (A. **283**, 50).

(5) By the reaction of the monohalogen fatty acids with silver oxide, boiling alkalis, or even water. The conditions of the reaction are perfectly similar to those observed in the conversion of the alkylogens into alcohols.

$$CH_2ClCO_2H + H_2O = CH_2(OH)COOH + HCl.$$

The α-derivatives yield α-hydroxy-acids; the β-derivatives are occasionally changed to unsaturated acids by the splitting-off of a halogen acid, whilst the γ-compounds form γ-hydroxy-acids, which subsequently pass into lactones. γ-Halogen acids are converted directly into lactones by the alkali carbonates.

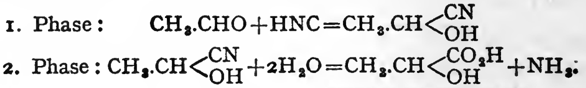
(6) By the action of nitrous acid on amido-acids:

$$\underset{\text{Aminoacetic Acid.}}{CH_2(NH_2).CO_2H}+HNO_2=\underset{\text{Hydroxyacetic Acid.}}{CH_2(OH).CO_2H}+N_2+H_2O.$$

(7) The hydroxy-acids can be obtained from the diazo-fatty acids, on boiling them with water or dilute acids.

(8) From the α-ketone-alcohols—*e.g.* butyroïn and isovaleroïn (p. 342)—on treating them with alkalis and air.

Nucleus-synthetic Methods of Formation.—(9) By allowing hydrocyanic acid and hydrochloric acid to act on the aldehydes and ketones. At first hydroxycyanides, the nitriles of hydroxy-acids (*q.v.*), are produced after which hydrochloric acid changes the cyanogen group into carboxyl:



$$1.\ \text{Phase:}\quad CH_3.CHO+HNC=CH_3.CH{<}{}^{CN}_{OH}$$
$$2.\ \text{Phase:}\ CH_3.CH{<}{}^{CN}_{OH}+2H_2O=CH_3.CH{<}{}^{CO_2H}_{OH}+NH_3.$$

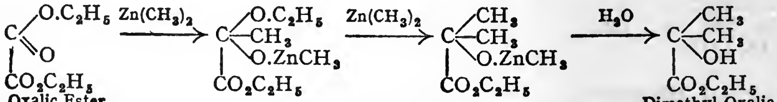
α-Hydroxypropionic Acid.

In preparing the hydroxycyanides, the aldehydes or ketones are treated with pure hydrocyanic acid, or powdered potassium cyanide may be added to the ethereal solution of the ketone, followed by the gradual addition of concentrated hydrochloric acid (B. **14,** 1965; **15,** 2318). The concentrated hydrochloric acid changes the cyanides to acids, the amides of the acids being at first formed in the cold, but on boiling with more dilute acid they undergo further change to acids. Sometimes the change occurs more readily by heating with a little dilute sulphuric acid. Ethylene oxide behaves like acetaldehyde with hydrocyanic acid.

(10) The glycol chlorhydrins (p. 319) undergo a similar alteration through the action of potassium cyanide and acids:

$$1.\ \text{Phase:}\ CH_2(OH).CH_2Cl+KNC\ =CH_2(OH)CH_2.CN+KCl,$$
$$2.\ \text{Phase:}\ CH_2(OH).CH_2CN+2H_2O=\underset{\beta\text{-Hydroxypropionic Acid.}}{CH_2(OH).CH_2.CO_2H}+NH_3.$$

(11) A method of ready applicability in the synthesis of *a*-hydroxy-acids consists in acting on diethyl oxalic ester with zinc and alkyl iodides (*Frankland* and *Duppa*). This reaction is like that in the formation of tertiary alcohols from the acid chlorides by means of zinc ethyl, or of the secondary alcohols from formic esters (p. 106)—1 and 2 alkyl groups are introduced into one carboxyl group (A. 185, 184):



Oxalic Ester. Dimethyl Oxalic Ester.

If we employ two alkyl iodides, two different alkyls may be introduced.

The acids obtained, as indicated, are named in accordance with their derivation from oxalic acid, but it would be more correct to view them as derivatives of hydroxyacetic acid or glycollic acid, $CH_2(OH).CO_2H$, and designate, *e.g.* dimethyl oxalic acid, as dimethyl hydroxyacetic acid.

(12*a*) β-Hydroxy-acids are formed when aldehydes or ketones are condensed with α-halogen fatty acid esters by means of zinc or magnesium; *e.g.* propionic aldehyde and α-bromopropionic ester yield α-methyl β-ethyl hydracrylic acid,

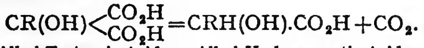
$C_2H_5CH(OH)CH(CH_3)COOH$; trioxymethylene, α-bromisobutyric ester and zinc yield αα-dimethyl hydracrylic acid (comp. p. 287) (C. 1901, I. 1196; II. 30; 1902, I. 856).

(12*b*) Ketone acid esters and magnesium alkyl iodides produce, in part, tertiary hydroxy-acid esters; also, ethyl chloroglyoxylate with magnesium alkyl halides yields the oxalic ether of the α-hydroxy-acid ester (C. 1902, II. 1359; 1900, II. 1110):

$$CH_3COCO_2C_2H_5+CH_3MgI=(CH_3)_2C(OMgI)CO_2C_2H_5$$
$$2C_2H_5OCO.COCl+2CH_3MgI=C_2H_5OCO.C(CH_3)_2O.CO.CO_2C_2H_5+2MgClI.$$

(13) When sodium or sodium ethoxide acts on the acetic esters and propionic esters it converts them into β-ketone-carboxylic esters, but in the case of butyric and isobutyric esters it produces the ether esters of β-hydroxy-acids, such as *ethoxycaprylic ester*, $(CH_3)_2CH.CH(OC_2H_5).C(CH_3)_2CO_2C_2H_5$, from isobutyric ester (A. **249**, 54).

Cleavage-Reactions.—(14) The fatty acids are formed from alkyl malonic acids, $CRR'(CO_2R)_2$, by the withdrawal of a carboxyl group (p. 253), and the hydroxy-fatty acids are obtained in a similar manner from alkyl hydroxymalonic acids or tartronic acids:



$$CR(OH)<^{CO_2H}_{CO_2H}=CRH(OH).CO_2H+CO_2.$$

Alkyl Tartronic Acid. Alkyl Hydroxyacetic Acid.

Isomerism.—The possible cases of isomerism with the hydroxy-acids are most simply deduced by considering the hydroxy-acids as the mono-hydroxyl substitution products of the fatty acids. Then the isomers are the same as the mono-halogen fatty acids, which may be regarded as the haloid esters of the alcoholic acids corresponding with them.

Hydroxyacetic or glycollic acid is the only acid which can be obtained from acetic acid:

$CH_3.COOH$	$CH_2OH.COOH$
Acetic Acid.	Glycollic Acid (p. 362).

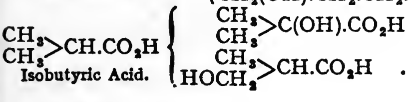
Propionic acid yields two hydroxypropionic acids:

$CH_3CH_2.COOH$	$CH_3\overset{*}{C}H(OH).COOH$	$CH_2(OH)CH_2.COOH$
Propionic Acid.	α-Hydroxypropionic Acid ord. Lactic Acid (p. 362).	β-Hydroxypropionic Acid Hydracrylic Acid (p. 369).

These are distinguished as α- and β-hydroxypropionic acids respectively. The α-acid contains an asymmetric carbon atom, and therefore, theoretically, should yield an inactive variety, which can be resolved, and two optically active modifications: these, in fact, exist.

Normal butyric acid yields three and isobutyric acid two mono-carboxylic acids:

$CH_3.CH_2.CH_2CO_2H$ n-Butyric Acid.	$CH_3.CH_2.CH(OH).CO_2H$	α-Hydroxybutyric Acid (p. 365)
	$CH_3.CH(OH).CH_2.CO_2H$	β-Hydroxybutyric Acid (p. 370)
	$CH_2(OH).CH_2.CH_2.COOH$	γ-Hydroxybutyric Acid (p. 374)



$\begin{matrix}CH_3\\CH_3\end{matrix}>CH.CO_2H$ Isobutyric Acid. $\left\{\begin{matrix}\begin{matrix}CH_3\\CH_3\end{matrix}>C(OH).CO_2H\\ \begin{matrix}CH_3\\HOCH_2\end{matrix}>CH.CO_2H\end{matrix}\right.$

. . . α-Hydroxyisobutyric Acid (p. 365)

. . . β-Hydroxyisobutyric Acid (unknown).

These alcohol-acids are divided into—

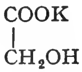
Primary acids: Glycollic acid, hydracrylic acid, γ-hydroxybutyric acid, β-hydroxyisobutyric acid.

Secondary acids: α-hydroxypropionic acid, α-hydroxybutyric acid, β-hydroxybutyric acid.

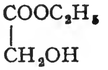
Tertiary acids: α-Hydroxyisobutyric acid.

Properties.—The hydroxy-fatty acids containing one OH group are, in consequence, more readily soluble in water, and less soluble in ether than the parent acids (p. 251). They are less volatile and, as a general rule, cannot be distilled without decomposition.

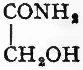
Reactions.—(1) The alcohol-acids behave like the monocarboxylic acids, in that they yield, through a change in the carboxyl group, normal salts, esters, amides, and nitriles :



$$\begin{array}{c}COOK\\ |\\ CH_2OH\end{array}$$



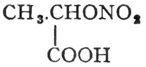
$$\begin{array}{c}COOC_2H_5\\ |\\ CH_2OH\end{array}$$



$$\begin{array}{c}CONH_2\\ |\\ CH_2OH\end{array}$$

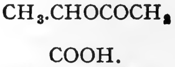
$$\begin{array}{c}CN\\ |\\ CH_2OH.\end{array}$$

(2) The remaining OH-group behaves like that of the alcohols, of which the hydrogen may be replaced by alkali metals and alkyls ; by acid radicals such as NO_2, by the action of a mixture of concentrated nitric and sulphuric acids ; or by a carboxylic acid residue, by the action of acid chlorides and anhydrides, such as the acetyl residue by means of acetyl chloride and anyhdride,



$$\begin{array}{c}CH_3.CHONO_2\\ |\\ COOH\end{array}$$

Nitrolactic Acid.

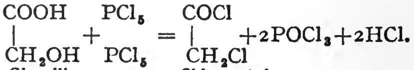


$$\begin{array}{c}CH_3.CHOCOCH_3\\ \\ COOH.\end{array}$$

Acetyl Lactic Acid.

Both of these reactions are characteristic of the hydroxyl groups of the alcohols (p. 323).

(3) PCl_5 replaces the two hydroxyl groups by chlorine :

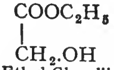


$$\begin{array}{c}COOH\\ |\\ CH_2OH\end{array} + \begin{array}{c}PCl_5\\ \\ PCl_5\end{array} = \begin{array}{c}COCl\\ |\\ CH_2Cl\end{array} + 2POCl_3 + 2HCl.$$

Glycollic Acid. Chloracetyl Chloride.

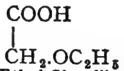
The acid chlorides corresponding with the hydroxy-acids are not known. Instead of these we get the chlorides of the corresponding monochloro-fatty acids, in which the chlorine in union with CO is very reactive with water and alcohols, yielding free acids and their esters ; in the case cited, monochloracetic acid, $CH_2Cl.CO_2H$, and its esters result. The remaining chlorine atom is, on the contrary, more firmly united, as in chlorethane.

In addition to ethyl glycollic ester there are ethyl glycollic acid and ethyl etho-glycollic ester :



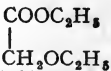
$$\begin{array}{c}COOC_2H_5\\ |\\ CH_2.OH\end{array}$$

Ethyl Glycollic Ester.



$$\begin{array}{c}COOH\\ |\\ CH_2.OC_2H_5\end{array}$$

Ethyl Glycollic Acid.



$$\begin{array}{c}COOC_2H_5\\ |\\ CH_2OC_2H_5.\end{array}$$

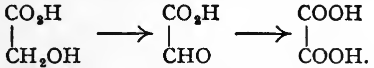
Ethyl Etho-glycollic Ester.

Alkalis cause the alkyl combined with CO_2 to separate, forming ethyl glycollic acid.

(4) The hydroxy-acids are reduced to their corresponding fatty acids (p. 252) when they are heated with hydriodic acid.

(5) Whilst in the preceding transpositions all the hydroxy-acids react similarly, the primary, secondary and tertiary alcohol-acids show marked differences when they are oxidized.

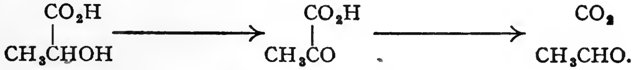
(*a*) The *primary* hydroxy-acids yield, by oxidation, aldehyde acids:



$$\begin{matrix}CO_2H\\ |\\ CH_2OH\end{matrix}\longrightarrow\begin{matrix}CO_2H\\ |\\ CHO\end{matrix}\longrightarrow\begin{matrix}COOH\\ |\\ COOH.\end{matrix}$$

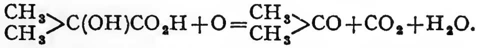
Glycollic Acid. Glyoxylic Acid. Oxalic Acid.

(*b*) The *secondary* hydroxy-acids yield ketone acids: the α-ketonic acids change to aldehyde and CO_2, the β-ketonic acids to ketones and CO_2:



$$\begin{matrix}CO_2H\\ |\\ CH_3CHOH\end{matrix}\longrightarrow\begin{matrix}CO_2H\\ |\\ CH_3CO\end{matrix}\longrightarrow\begin{matrix}CO_2\\ \\ CH_3CHO.\end{matrix}$$

(*c*) *Tertiary* α-hydroxy-acids yield ketones:



$$\begin{matrix}CH_3\\ CH_3\end{matrix}{>}C(OH)CO_2H+O=\begin{matrix}CH_3\\ CH_3\end{matrix}{>}CO+CO_2+H_2O.$$

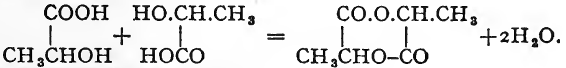
(6) The *a*-hydroxy-acids undergo a similar decomposition when heated with dilute sulphuric or hydrochloric acid or by action of concentrated H_2SO_4. Their carboxyl group is removed as formic acid (when concentrated H_2SO_4 is employed, CO and H_2O are the products):

$$(CH_3)_2C(OH)CO_2H=(CH_3)_2CO+HCO_2H$$
$$CH_3CH(OH)CO_2H=CH_3.CHO+HCO_2H.$$

Another alteration is undergone by the *a*-hydroxy-acids at the same time, which, however, does not extend far: water is eliminated, and unsaturated acids are produced. This change is easily effected when PCl_3 is allowed to act on the esters of α-hydroxy-acids (p. 291).

(7) Especially interesting is the behaviour of the α-, β-, γ-, or δ-hydroxy-acids in respect to the elimination of water from carboxyl and alcoholic hydroxyl groups.

(*a*) The ***α-hydroxy-acids*** lose water when they are heated and become *cyclic double esters*—the *lactides*—in the formation of which two molecules of the α-hydroxy-acid have taken part:



$$\begin{matrix}COOH & & HO.CH.CH_3\\ | & + & |\\ CH_3CHOH & & HOCO\end{matrix}=\begin{matrix}CO.O.CH.CH_3\\ |\qquad\quad |\\ CH_3CHO{-}CO\end{matrix}+2H_2O.$$

α-Hydroxypropionic Acid or Lactic Acid. Lactide.

(*b*) When the *β-hydroxy-acids* are heated alone, water is withdrawn and unsaturated acids are the products (p. 291; C. 1897, I. 363):

$$CH_2(OH).CH_2CO_2H = CH_2:CHCO_2H+H_2O.$$

β-Hydroxypropionic Acid
Hydracrylic Acid.
Acrylic Acid.

(*c*) The γ- and *δ-hydroxy-acids* lose water at the ordinary temperature, and change more or less completely into simple *cyclic esters*—the γ- and δ-lactones.

The α-, β-, γ- and δ-amido-carboxylic acids corresponding with the α-, β-, γ- and δ-hydroxy-acids, show differences similar to those manifested by the latter.

STRUCTURE OF NORMAL CARBON CHAINS AND THE FORMATION OF LACTONES

The peculiar differences in the behaviour of the α-, β-, γ- and δ-hydroxy-acids when they split off water have contributed to the development of a representation of the spacial arrangement or configuration of carbon chains (B. **15**, 630). The assumption that the atoms of a molecule not linked to each other in a formula can exert an affinity upon one another has led to the idea that, in a union of more than two C atoms, these atoms arrange themselves not in a straight line, but upon a curve. We can then comprehend that cyclic, simple ester formation can not take place between the first and second carbon atoms, rarely between the second and third, but readily between the first and fourth or first and fifth carbon atoms, which have approached so near to each other that an oxygen atom is capable of bringing about a closed ring (see Alkylene Oxide, p. 317, and Alkylene Imines, p. 334, as well as the *strain theory* of *v. Baeyer* in the introduction to the carbocyclic derivatives, Vol. II.).

A. SATURATED HYDROXYMONO-CARBOXYLIC ACIDS, HYDROXY-PARAFFIN MONOCARBOXYLIC ACIDS

α-Hydroxy-acids.

(1) **Glycollic Acid,** *Hydroxyacetic Acid* [Ethanol Acid], $CH_2.OH.COOH$, m.p. 80°, occurs in unripe grapes and in the green leaves of Virginia creeper, *Ampelopsis hederacea.*

History.—Glycollic acid was first obtained in 1848 by *Strecker* from *amino-acetic acid* or *glycocoll*—hence the name—according to the sixth method of formation (p. 358). In 1856 *Debus* discovered it together with glyoxal and glyoxylic acid among the oxidation products obtained from *ethyl alcohol* by the action of nitric acid. *Würtz* in 1857 observed its formation in the oxidation of *ethylene glycol,* and *Kekulé* in 1858 showed how it could be made by boiling a solution of *potassium chloracetate* (A. **105,** 286; comp. B. **16,** 2414; A. **200,** 75; B. **26,** R. 606).

It is also produced by the action of potassium hydroxide on *glyoxal* (p. 346); by the reduction of *oxalic acid* method of formation (No. 2, p. 357), and from *diazoacetic ester* (method of formation No. 7). Its nitrile results when hydrocyanic acid acts on *formaldehyde* (method No. 9), and is converted by hydrochloric acid into glycollic acid. It is also formed with hexamethylene tetramine when formaldehyde is warmed with KNC (C. 1900, I. 402). It also appears in the oxidation of glycerol and dextrose by silver oxide.

Glycollic acid crystallizes from acetone. It is very soluble in water and alcohol. Diglycollide and polyglycollide (p. 367) are produced when it is heated. Nitric acid oxidizes it to oxalic acid. When heated with concentrated sulphuric acid, glycollic acid decomposes into trioxymethylene (*metaformaldehyde,* p. 199), carbon monoxide and water).

Calcium Salt, $(CH_2OHCO_2)_2Ca+3H_2O$; *ethyl ester,* $CH_2OH.CO_2C_2H_5$, b.p. 160°.

Trichlorethyl alcohol (p. 117) can be regarded as being the chloride of orthoglycollic acid.

(2) **Lactic Acid of Fermentation,** *α-Hydroxypropionic Acid, Ethylidene Lactic Acid,* [d+l] *Lactic Acid* [2-Propanol Acid], $CH_3CH(OH)CO_2H$, m.p. 18°, b.p.$_{12}$ 120° (B. **28,** 2597), is isomeric with *β-hydroxypropionic acid, hydracrylic acid,* [3-propanol acid], $CH_2OH.CH_2CO_2H$, which will be discussed later as the first β-hydroxy-acid.

Lactic Acid is formed by a special fermentation, the lactic acid fermentation of lactose, sucrose, gum and starch. It is, therefore, contained in many substances which have soured—*e.g.* in sour milk, in sauerkraut, pickled cucumbers, common (or lesser) centaury (*Erythroca centaurium*), also in the gastric juice.

Methods of Formation.—The acid is artificially prepared by the methods already described: (1) from α-propylene glycol; (2) from pyroracemic acid; (5) from α-chloro- or bromo-propionic acid; (6) from alanine; (9) from acetaldehyde and hydrocyanic acid; (13) by heating isomalic acid, $CH_3C(OH)(COOH)_2$ (B. **26**, R. 7).

Other methods of formation are: the action of heat on dextrose or sucrose with water and 2–3 parts of barium hydroxide at 160°; prolonged contact of hexoses with dilute sodium hydroxide solution (B. **41**, 1009); the interaction of pentoses, such as arabinose and xylose with warm potassium hydroxide solution (B. **35**, 669); heating α-dichloracetone, $CH_3.CO.CHCl_2$, with water at 200°, and oxidation of acetol (p. 341), all depend on the transformation of pyroracemic aldehyde.

Lactic Acid Fermentation.—This fermentation is induced in sugar solutions by a particular ferment, the lactic acid bacillus, *Bacillus acidi lacti*, which is present in decaying cheese. It proceeds most rapidly at temperatures ranging from 35° to 45° (C. 1897, II. 338). It is noteworthy that the bacillus is very sensitive to free acid. The fermentation is arrested when sufficient lactic acid is produced, but is again renewed when the acid is neutralized. Therefore, zinc or calcium carbonate (C. 1897, II. 20, 937) is added at the beginning, and the lactic acid thus obtained either as the calcium or zinc salt. Should the fermentation continue for some time, the lactic will pass into butyric fermentation, the insoluble calcium lactate will disappear, and the solution will at last contain calcium butyrate (comp. n-Butyric Acid, p. 259). On the formation of lactic acid as an intermediate product in the fermentation of dextrose to alcohol and CO_2, see B. **37**, 421; A. **349**, 125.

History.—*Scheele* (1780) discovered lactic acid in sour milk. In 1847 *Liebig* demonstrated that the *sarcolactic acid* found by *Berzelius* (1808) in the fluids of the muscles was different from the *lactic acid of fermentation*. *Würtz* (1858) described the formation of fermentation lactic acid from α-propylene glycol and air in the presence of platinum black, and recognized that it was a dibasic acid. *Kolbe* (1859) obtained lactyl chloride by the action of PCl_5 on calcium lactate. This body is identical with chloropropionyl chloride, and lactic acid is therefore monobasic and must be considered as hydroxypropionic acid. Later (1860) *Würtz* called it a diatomic, monobasic acid, meaning to indicate thereby that one of the two typical hydrogen atoms is more basic than the other. "But it is much more significant when *Kekulé* declares that it is simultaneously an acid and an alcohol" (B. **20**, R. 948). *Strecker* was the first to synthesize the acid from synthetic amidolactic acid or alanine, which had also been prepared by him through the interaction of hydrazonic acid and aldehyde ammonia.

Fermentation lactic acid is a syrup soluble in water, alcohol and ether, and is optically inactive (C. 1905, II. 1527). Placed in a desiccator over sulphuric acid, it partially decomposes into water and its anhydride. When distilled it yields lactide (p. 367), aldehyde, carbon monoxide and water.

Heated to 130° with dilute sulphuric acid, it decomposes into aldehyde and formic acid; when oxidized with $KMnO_4$, it yields pyroracemic acid; whilst with chromic acid, acetic acid and carbon dioxide are formed. Heated with hydrobromic acid, it changes to α-bromopropionic acid.

Hydriodic acid at once reduces it to propionic acid, and PCl_5 changes it into chloropropionyl chloride (p. 360).

Lactates.—The *sodium salt*, $CH_3CH(OH)CO_2Na$, is an amorphous mass. When heated with metallic sodium, *disodium compound*, $CH_3CH(ONa)CO_2Na$, results; *calcium salt*, $(C_3H_5O_3)_2Ca+5H_2O$, is soluble in ten parts of cold water, and is very readily dissolved by hot water; *zinc salt*, $(C_3H_5O_3)_2Zn+3H_2O$, dissolves in 58 parts of cold and 6 parts of hot water; *iron salt*, $(C_3H_5O_3)_2Fe+3H_2O$.

The *chloride of ortholactic acid*, $CH_3CH(OH)CCl_3$, m.p. 50°, b.p. 161°, has already (p. 118) been referred to as trichlorisopropyl alcohol. It is also obtained from chloral by means of methyl magnesium iodide, and constitutes the soporific *Isopral.* With sodium ethoxide it forms ethyl α-ethyl lactate (p. 366) (C. 1904, I. 636; 1905, I. 344; B. **40,** 212).

The Optically Active Lactic Acids.

The optically inactive, fermentation lactic acid contains an asymmetric carbon atom indicated in the formula $CH_3.\overset{*}{C}H(OH)CO_2H$ by the small star. The acid can be resolved by strichnine, morphine, or quinine, into two optically active components,—dextro-lactic (*d*-) acid and lævo-lactic (*l*-) acid,—possessing similar but opposite rotary power. The strychnine salt of the lævo-acid crystallizes out first, whilst the quinine salt of the dextro-acid is obtained first (B. **24,** R. 794; C. 1906, I. 1150; II. 499).

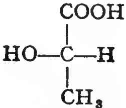
It must be noticed again here, *that those optically inactive compounds which can be split into two optically active isomers or can be formed from these, are referred to as racemic* [*d*+l] *modifications* (comp. p. 56).

On mixing solutions of equal quantities of lævo- and dextro-lactate of zinc, the zinc salt of fermentation lactic acid will be produced, and, being more insoluble, will crystallize out. The dextro-modification will remain, if *Penicillium glaucum* is permitted to grow in the solution of inactive ammonium lactate (B. **16,** 2720), whilst the lævo-rotatory modification is produced in the breaking down of a sucrose solution by *Bacillus acidi lævolactici* (B. **24,** R. 150).

The active lactic acids are connected with the active α-bromopropionic acids (p. 288) in the following manner: *d*-bromopropionic acid with potassium hydroxide solution gives *d*-lactic acid; silver carbonate, however, produces the *l*-acid; the *l*-bromopropionic acid behaves *vice versâ* (comp. Walden's *Inversion*, p. 55; and B. **100,** 1193):

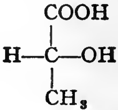
$$\begin{tikzcd}
d\text{-Bromopropionic acid} \arrow[r, "KOH"] \arrow[d, "Ag_2O"'] & d\text{-Lactic acid} \\
l\text{-Lactic acid} \arrow[r, "KOH"] & l\text{-Bromopropionic acid} \arrow[u, "Ag_2O"']
\end{tikzcd}$$

d-Alanine (*d*-α-aminopropionic acid, p. 389) yields, with nitrous acid, *d*-lactic acid. This provides a link between *d*-lactic acid and tartaric acid, wherefrom the probable configuration for *d*- and *l*-lactic acid is obtained (comp. also p. 31; against this, however, B. **41,** 894):



$$\begin{array}{c} COOH \\ | \\ HO—C—H \\ | \\ CH_3 \end{array}$$

d-Lactic Acid.



$$\begin{array}{c} COOH \\ | \\ H—C—OH \\ | \\ CH_3 \end{array}$$

-Lactic Acid.

On *d*-alanine, *l*-serine, *d*-glyceric acid, etc., see B. **50,** 3718.

Sarcolactic Acid, *Dextro-lactic Acid, Paralactic Acid,* was discovered in 1808 by *Berzelius* in the fluid of the muscles, and shown by

Liebig (1848) to be different from the lactic acid of fermentation. It is present in different animal organs, and is most conveniently obtained from Liebig's beef-extract.

Sarcolactic acid is also formed during butyric fermentation (p. 259) by the *granulo-bacillus* and other butyric ferments (C. 1900, I. 777).

Dextro- and lævo-lactic acid, m.p. 26° approx., are very hygroscopic bodies. Alkali converts the *l*-acid very rapidly into the [*d*+*l*] modification, whilst the *d*-acid is changed more slowly (C. 1904, II. 641).

The rotation of an approximately 1·24 per cent. solution of the crystallized acid in water is ±2·24° (C. 1906, I. 1150).

The dextro- and lævo-lactates of *zinc* crystallize with 2 molecules of water $(C_3H_5O_3)_2Zn+2H_2O$. For other salts, see B. **29**, R. 899. Zinc *d*-lactate rotates the plane of polarization to the *left*, whilst the *l*-lactate rotates it to the *right*: $[\alpha]_D^{20}=\pm 8{\cdot}6^\circ$.

Homologous α-Hydroxy-acids.—The homologous α-hydroxy-acids are, from the very nature of things, either secondary or tertiary alcohol acids. Glycollic acid is the only primary α-alcohol acid. (*a*) The *secondary alcohol acids* are generally formed (1) from the corresponding α-halogen fatty acids (method 5); (2) *nucleus-synthetic*, from aldehydes and hydrocyanic acid, and subsequent saponification of the nitriles of the hydroxy-acids by means of hydrochloric acid (method 9). (*b*) The *tertiary hydroxy-acids* result—

(1) From the oxidation of dialkyl acetic acid (general method 3).

(2) Upon treating *a*-ketone alcohols with alkalis and air (method 8, p. 358).

(3) By the action of hydrocyanic acid and hydrochloric acid on ketones (method 9).

(4) When zinc and alkyl iodides react with oxalic ester (method 11, p. 358).

(5) From α-ketone-acid esters and magnesium alkyl halides (C. 1902, II. 1359).

Hydroxybutyric Acids.—Four of the five possible isomers are known; two of these are α-hydroxy-acids: (1) *α-Hydroxybutyric Acid*, $CH_3CH_2CH(OH)CO_2H$, m.p. 43°, has been resolved by brucine into its optically active components (B. **28**, R. 278, 325, 725). (2) *α-Hydroxyisobutyric Acid, Butyl Lactic Acid, Acetonic Acid, Dimethyl Oxalic Acid* [2-Methyl-2-propanol Acid], $(CH_3)_2C(OH)COOH$, m.p. 79°, b.p. 212°, is obtained from dimethyl acetic acid, from acetone and from oxalic ester (see above); hence the names acetonic acid and dimethyl oxalic acid. It is produced when *β*-isoamylene glycol is oxidized by nitric acid, and is obtained from α-bromo- and α-amidobutyric acid as well as from amyl pyroracemate and CH_3MgI, and from acetone chloroform. It occurs in the urine during *acetonuria* (C. 1899, II. 63).

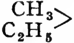
Acetone Chloroform, $(CH_3)_2C(OH)CCl_3$, m.p. 91°, b.p. 167°, is obtained by the union of acetone and chloroform in the presence of alkali hydroxides. It is a derivative of α-hydroxyisobutyric acid, the chloride of ortho-α-hydroxyisobutyric acid (p. 235) which stands in the same relation to α-hydroxyisobutyric acid that chloroform does to formic acid. Aqueous alkalis convert it into α-hydroxylisobutyric acid (*Willgerodt*, B. **20**, 2445; **29**, R. 908; C. 1898, II. 277; 1902, I. 176). It acts as an anæsthetic and an antiseptic.

In the presence of phenols and sodium hydroxide solution, acetone and chloroform yield α-phenoxyisobutyric acids, $C_2H_5OC(CH_3)_2COOH$ (C. 1916, II. 326).

α-Hydroxyvaleric Acids:

α-Hydroxy-n-valeric Acid, $CH_3.CH_2.CH_2.CH(OH).CO_2H$, m.p. 28–29° (B. **18**, R. 79).

α-Hydroxyisovaleric Acid, $(CH_3)_2.CH.CH(OH).CO_2H$, m.p. 86°, is prepared from dimethyl pyroracemic acid (p. 408) (A. **205**, 28; B. **28**, 296; C. 1902, I. 251).



Methyl Ethyl Glycollic Acid, $\begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>C(OH).CO_2H$, m.p. 68° (A. **204**, 18).

α-Hydroxycaproic Acids, *α-Hydroxy-n-caproic Acid*, $CH_3[CH_2]_3CH(OH)COOH$, m.p. 61°, is prepared from α-bromo- or α-amino-n-caproic acid. *α-Hydroxy-iso-*

caproic Acid, Leucic Acid, $(CH_3)_2CH.CH_2CH(OH)COOH$, m.p. 73°, is obtained. from leucine (p. 389) by means of nitrous acid (*Strecker,* 1848). *α-Hydroxy-diethyl Acetic Acid, Diethyl Oxalic Acid,* $(C_2H_5)_2C(OH).COOH$, m.p. 80° (A. **200,** 21). *α-Hydroxy-methyl Isopropyl Acetic Acid,* $(CH_3)_2CH.C(CH_3)(OH)COOH$, m.p. 63° (C. 1898, I. 202). *α-Hydroxy-tert.-butyl Acetic Acid,* $(CH_3)_3C.CH(OH)COOH$, m.p. 87°, is obtained from trimethyl pyroracemic acid (p. 408) by reduction.

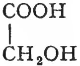
Higher α-Hydroxy-fatty Acids: *β-Diethyl Ethylidene Lactic Acid,* $(C_2H_5)_2$-$CH.CH(OH)COOH$, m.p. 82°, is prepared from γ-bromo-γ-acetoxy-α-diethyl acetoacetic ester, $(C_2H_5)_2C(COOR)CO.CHBr(OCOCH_3)$, by means of the cleaving influence of dilute sulphuric acid (B. **31,** 2953). *α-Hydroxy-n-caprylic Acid,* $CH_3[CH_2]_5CH(OH)COOH$, m.p. 69·5°, is obtained from œnanthol. *Di-n-propyl Glycollic Acid, α-Hydroxy-di-*n*-propyl Acetic Acid,* $(C_3H_7)_2C(OH)COOH$, m.p. 72°, is prepared from butyroïn (p. 342) (B. **23,** 1273). *Di-isopropyl Oxalic Acid, α-Hydroxy-di-isopropyl Acetic Acid,* $(C_3H_7)C(OH)COOH$, m.p. 111° (B. **28,** 2463). *Di-isobutyl Glycollic Acid* $(C_4H_9)_2C(OH)COOH$, m.p. 114°. *Methyl Nonyl Glycollic Acid,* $(C_9H_{19})C(CH_3)(CH)COOH$, m.p. 46°, is obtained from methyl nonyl ketone (C. 1902, I. 744).

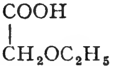
α-Bromo-fatty acids have yielded the following: *α-Hydroxylauric Acid,* $C_{18}H_{22}(OH)COOH$, m.p. 74° (C. 1904, I. 261); *α-Hydroxymyristic Acid,* $C_{13}H_{26}$-$(OH).CO_2H$, m.p. 51° (B. **22,** 1747); *α-Hydroxypalmitic Acid,* $C_{15}H_{30}(OH)CO_2H$, m.p. 82° (B. **24,** 939); *α-Hydroxystearic Acid,* $C_{17}H_{34}(OH)CO_2H$, m.p. 85° (B. **24,** 2388).

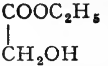
In the following pages those α-hydroxy-acid derivatives will be described which belong to glycollic and lactic acids.

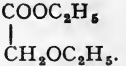
Alkyl Derivatives of the α-Hydroxy-acids.

A single α-hydroxy-acid yields three kinds of alkyl derivatives: *ethers, esters* and *ether-esters :*


$$\begin{array}{l} COOH \\ | \\ CH_2OH \end{array}$$
Glycollic Acid.


$$\begin{array}{l} COOH \\ | \\ CH_2OC_2H_5 \end{array}$$
Ethyl Glycollic Acid.


$$\begin{array}{l} COOC_2H_5 \\ | \\ CH_2OH \end{array}$$
Glycollic Ethyl Ester.


$$\begin{array}{l} COOC_2H_5 \\ | \\ CH_2OC_2H_5. \end{array}$$
Ethyl Glycollic Ethyl Ester.

(1) The **alkyl-ethers** of the α-hydroxy-acids are obtained (1) by the action of sodium alcoholates on salts of the α-halogen substitution products of the fatty acids; (2) by the saponification of the dialkyl ether esters or alkyl ether nitriles (p. 380) of the α-hydroxy-acids.

Methyl-ether Glycollic Acid, $CH_3OCH_2.COOH$, b.p. 198°. *Ethyl Glycollic Acid,* b.p. 206–207°; *chloride,* b.p. 128° (J. pr. Ch. [2] **65,** 479; C. 1907, I. 871). *α-Ethoxyl Propionic Acid,* $CH_3CH(OC_2H_5).CO_2H$, b.p. with partial decomposition 195–198°. It is split up by means of cinchonidine or morphine into its two optical components, which are remarkable for their large rotations.

(2) **Alkyl Esters** of the α-hydroxy-acids result (1) on heating the free acids with absolute alcohol; (2) when the cyclic double esters, the lactides, are heated with alcohols. *Glycollic Methyl Ester,* $CH_2(OH)COOCH_3$, b.p. 151°. *Glycollic Ethyl Ester,* b.p. 160°. *Lactic Methyl Ester,* $CH_3CH(OH)CO_2CH_3$, b.p. 145°. *Lactic Ethyl Ester,* b.p. 154·5°.

(3) The **dialkyl-ethyl esters** of the α-hydroxy-acids are produced (1) when sodium alcoholates act on the esters of α-halogen fatty acids; (2) by the interaction of alkylogens and the sodium derivatives of the alkyl esters of the α-hydroxy-acids.

Methyl Glycollic Methyl Ester, $CH_2(OCH_3).COOCH_3$, b.p. 127°; *ethyl ester,* b.p. 131°. *Ethyl Glycollic Methyl Ester,* $CH_2(O.C_2H_5)CO.OCH_3$, b.p. 148°. *Ethyl Glycollic Ethyl Ester,* b.p. 152° (B. **17,** 486). *Methyl Lactic Methyl Ester,* $CH_3CH(OCH_3)COOCH_3$, b.p. 135–138°; *ethyl ester,* b.p. 135·5°. *Ethyl Lactic Ethyl Ester,* $CH_3.CH(OC_2H_5).COOC_2H_5$, b.p. 155° (A. **197,** 21; B. **40,** 212).

Anhydride Formation of the α-Hydroxy-Acids.

Since the α-alcohol-acids possess the characteristics of both carboxylic acids and alcohols, they are capable of forming various types of anhydrides. These may occur between the alcoholic groups of two molecules (*dicarboxylated ethers* or *ether acids*), between the carboxylic groups, between the alcoholic groups (*dihydroxylated carboxylic anhydrides* and *ether carboxylic anhydrides*), and, finally, between the alcohol group of one molecule and the carboxylic group of a second (*alcohol ester acids* or *semilactides* and *cyclic double esters* or *lactides*). The best example for examination is glycollic acid.

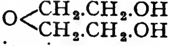
1.  $O{<}\begin{matrix}CH_2COOH\\CH_2COOH\end{matrix}$ Alcohol anhydride of glycollic acid: *Diglycollic Acid.*

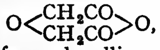
2.  $\begin{matrix}HOCH_2CO\\HOCH_2CO\end{matrix}{>}O$ Glycollic anhydride is not known.

3.  $O{<}\begin{matrix}CH_2CO\\CH_2CO\end{matrix}{>}O$ Alcohol- and acid-anhydride of glycollic acid: *Diglycollic Anhydride.*

4.  $\begin{matrix}HOCH_2CO\\HOCO.CH_2\end{matrix}{>}O$ Open ester acid: *Glycollo-glycollic Acid.*

5.  $O{<}\begin{matrix}CH_2CO\\COCH_2\end{matrix}{>}O$ Closed, cyclic double ester of glycollic acid: *Glycollide*, simplest *Lactide.*

Diglycollic Acid, the *alcohol anhydride of glycollic acid*, $C_4H_6O_5$, is formed together with glycollic acid on boiling monochloracetic acid with lime, baryta, magnesia, or lead oxide, and in the oxidation of diethylene glycol,  $O{<}\begin{matrix}CH_2.CH_2.OH\\CH_2.CH_2.OH\end{matrix}$ (p. 313). Diglycollic acid crystallizes with water in large rhombic prisms.

Diglycollic Anhydride,  $O{<}\begin{matrix}CH_2CO\\CH_2CO\end{matrix}{>}O$, m.p. 97°, b.p. 240°, is isomeric with glycollide. It is obtained from glycollic acid by a simultaneous alcohol-anhydride and acid-anhydride formation. It also results upon heating diglycollic acid, or by boiling it with acetyl chloride (A. **273**, 64).

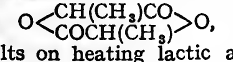
Dilactylic Acid, $O(CH_2CHCOOH)_2$, has received little attention.

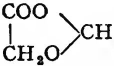
Glycolloglycollic Acid, $CH_2(OH)COOCH_2COOH$, generally termed *glycollic anhydride*, and *Lactylolactic Acid*, $CH_3CH(OH)COOCH(CH_3)COOH$, commonly called *lactic anhydride*, have not been well studied. They are produced when the free *a*-hydroxy-acids are heated to 100°, and constitute intermediate steps in the lactide formation (B. **23**, R. 325). Distillation of lactic acid produces lactyl lactic acid, lactide, and also *Lactyl Acetyl Lactic Acid*, $CH_3CH(OH)COOCH(CH_3)COOCH(CH_3)COOH$, m.p. 39°, b.p. 235–240° (C. 1905, I. 862).

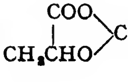
Lactides: Cyclic Double Esters of the α-Hydroxy-acids.

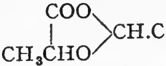
Diglycollide,  $O{<}\begin{matrix}CH_2CO\\COCH_2\end{matrix}{>}O$, m.p. 86°, is produced when polyglycollide is distilled under greatly reduced pressure. When heated at the ordinary pressure, or if kept, it reverts to polyglycollide, from which it differs by its lower melting point and ready solubility in chloroform. It combines readily with water (A. **279**, 45).

Polyglycollide, $(C_2H_2O_2)x$, m.p. 223°, is formed on heating glycollic acid, and when dry sodium chloracetate is heated alone to 150°. It passes into glycollic esters when heated with alcohols in sealed tubes (A. **279**, 45).

Lactide,  $O{<}\begin{matrix}CH(CH_3)CO\\COCH(CH_3)\end{matrix}{>}O$, m.p. 125°, b.p.$_{760}$ 255°, b.p.$_{12}$ 138° (B. **28**, 2595), results on heating lactic acid under diminished pressure. It can be recrystallized from chloroform (A. **167**, 318; B. **25**, 3511; **28**, 2595). *d-* and *l-Lactide*, m.p. 95° (C. 1906, I. 1329). The optical rotation of the lactic acids is increased greatly by lactide formation. Homologous lactides, see B. **26**, 263; A. **279** 100.

Cyclic Ether Esters.—*Glycollic Methylene Ester*,  $\begin{matrix}COO\\|\\CH_2O\end{matrix}{>}CH_2$, is obtained from glycollic acid and formaldehyde (C. 1901, II. 1261). *Glycollic Ethylene Ester*,  $\begin{matrix}COOCH_2\\|\quad\quad|\\CH_2OCH_2\end{matrix}$, m.p. 31°, b.p. 214° (B. **27**, 2945).

Methylene Lactate,  $\begin{matrix}COO\\|\\CH_3CHO\end{matrix}{>}CH_2$, b.p. 153° (B. **28**, R. 180).

Lactic Ethylidene Ester,  $\begin{matrix}COO\\ |\\ CH_3CHO\end{matrix}\!>\!CH.CH_3$, b.p. 151°, is produced when lactic acid and acetaldehyde are heated to 160°. Its hexachloro-derivative is chloralide (below).

Acid Esters of the α-Hydroxy-acids.

Nitroglycollic Acid, m.p. 54°, results, together with nitroglycollyl glycollic acid, $NO_2OCH_2COOCH_2COOH$, from glycollic acid and nitrosulphuric acid.

Nitrolactic Acid, $CH_3CHO(NO_2)COOH$, is a yellow liquid, decomposing at the ordinary temperature into oxalic and hydrocyanic acids (B. **12**, 1837; C. 1903, II. 488; 1904, I. 434). Mono-halogen acetic acid (p. 287) and α-halogen propionic acid (p. 288) are looked on as being *haloid acid esters* of *a*-hydroxy-acids.

Acetyl Glycollic Acid, $CH_2O(COCH_3)COOH$, m.p. 67°, b.p.$_{12}$ 145°, is obtained from glycollic acid and acetic anhydrides; *chloride,* b.p.$_{14}$ 54°; *ethyl ester,* $CH_2O(COCH_3)COOC_2H_5$, b.p. 179°. *Acetyl Lactic Acid,* $CH_3CH(OCOCH_3)$-$COOH$, m.p. 57–60°, b.p.$_{11}$ 127°, is prepared from lactic acid and acetyl chloride; *chloride,* b.p.$_{11}$ 56° (B. **36**, 466; **37**, 3971; **38**, 719; C. 1905, I. 1373).

Halogen α-Hydroxy-acids.

β-Monohalogen Ethylidene Lactic Acids.—*β-Chlorolactic Acid,* CH_2ClCH-$(OH)CO_2H$, m.p. 78°. *β-Bromolactic Acid,* $CH_2BrCHOHCO_2H$, m.p. 89°. *β-Iodolactic Acid,* $CH_2ICH(OH)CO_2H$, m.p. 100°. These three acids have been prepared by adding hydrogen chloride, bromide or iodide to *epihydrin* or *glycidic acid,* $\overline{CH_2CH(O})CO_2H$.

β-Chlorolactic acid is also formed from monochloraldehyde by the action of hydrocyanic acid and by the oxidation of *epichlorhydrin,* $\overline{CH_2CH(O})CH_2Cl$, and *α-chlorhydrin,* $CH_2ClCH(OH).CH_2OH$, with concentrated HNO_3; as well as by the addition of hypochlorous acid to acrylic acid (together with α-chlorhydracrylic acid).

Silver oxide converts it into glyceric acid; when reduced with hydriodic acid it becomes *β*-iodopropionic acid. Heated with alcoholic potassium hydroxide it is again changed to epihydric acid (see above), just as ethylene oxide is obtained from glycol chlorhydrin (p. 317).

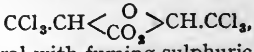
Higher halogen substitution products of the α-hydroxy-acids have been prepared by the progressive treatment of halogen aldehydes, like dichloraldehyde, chloral, bromal, and trichlorobutyric aldehyde, with hydrocyanic acid and hydrochloric acid. Trichlorolactic acid has been the most thoroughly studied.

β-DichlorolacticAcid, $CHCl_2.CH(OH).CO_2H$, m.p. 77°.

β-Trichlorolactic Acid, $CCl_3.CH(OH)CO_2H$, m.p. 105–110°, is soluble in water, alcohol and ether. Alkalis easily change it into chloral, chloroform and formic acid. Zinc and hydrochloric acid reduce it to dichlor- and mono-chloracrylic acids (p. 294).

Because trichlorolactic acid yields chloral without difficulty, it is converted quite readily, by different reactions, into derivatives of chloral, and also of glyoxal, probably by decomposition into dichloraldehyde and CO_2. It forms glyoxime with hydroxylamine, and glycosin with ammonia (p. 346, and B. **17**, 1997).

Trichlorolactic Ethyl Ester, $CCl_3CH(OH)COOC_2H_5$, m.p. 66°, b.p. 235°, is prepared from chloral cyanhydrin with alcohol and sulphuric or hydrochloric acid (B. **18**, 754).

Chloralide, *Trichlorethylidene Trichlorolactic Ester,*  $CCl_3.CH\!<\!\begin{matrix}O\\ CO_2\end{matrix}\!>\!CH.CCl_3$, m.p. 114°, b.p. 272°, was first prepared by heating chloral with fuming sulphuric acid to 105°, and subsequently when trichlorolactic acid was heated to 150° with excess of chloral. When heated to 140° with alcohol, it breaks up into trichlorolactic ester and chloral alcoholate (*Wallach*, A. **193**, 1). Chloral also unites with lactic and other hydroxy-acids, glycollic, malic, salicylic, etc., forming compounds very similar to that with trichlorolactic acid, known as *chloralides* (A. **193**, 1).

Tribromolactic Acid, $\mathrm{CBr_3.CH(OH)CO_2H}$, m.p. 141–143°, unites with chloral and bromal to corresponding chloralides and bromalides.

Trichlorovalerolactic Acid, $\mathrm{CH_3CCl_2CHCl.CH(OH).CO_2H}$, m.p. 140° (A. **179**, 99).

β-Hydroxycarboxylic Acids.

Generally the β-hydroxycarboxylic acids, when heated, part with water and become converted into unsaturated olefine carboxylic acids:

$$\underset{\text{Ethylene Lactic Acid or Hydracrylic Acid.}}{\mathrm{CH_2OH.CH_2.CO_2H}} \xrightarrow{-\mathrm{H_2O}} \underset{\text{Acrylic Acid.}}{\mathrm{CH_2{=}CHCO_2H}}.$$

In the case of the higher homologues of ethylene lactic acid, when water is eliminated, both αβ- and βγ-olefine carboxylic acids (B. **26**, 2079) result.

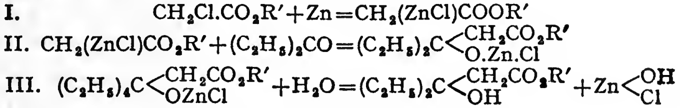
α-Dialkyl β-Hydroxy-acids and their esters are prepared from the dialkyl acetoacetic esters by reduction, and from aldehydes, α-bromodialkyl acetic esters by zinc. Those which possess no hydrogen atom in the α-position free to take part in the splitting off of water decompose in various ways: when heated, some are converted into a mixture of aldehydes and dialkyl acetic acids; others yield semilactides, such as the α-hydroxy-acids (p. 366) (C. 1904, I. 1134):

$$\underset{\alpha\text{-Diethyl-}\beta\text{-hydroxybutyric Acid.}}{\mathrm{CH_3CH(OH)C(C_2H_5)_2COOH}} = \mathrm{CH_3CHO} + \underset{\text{Diethyl Acetic Acid.}}{\mathrm{CH(C_2H_5)_2COOH}}$$

$$\underset{\text{Hydroxypivalic Acid.}}{\mathrm{CH_2(OH)C(CH_3)_2COOH}} \longrightarrow \mathrm{CH_2(OH)C(CH_3)_2COO[CH_2C(CH_3)_2COO]_4CH_2.C(CH_3)_2COOH}$$

The esters of such acids containing free hydrogen atoms attached to a carbon atom in the γ-position react with $\mathrm{P_2O_5}$ in a benzene solution and form βγ-olefine carboxylic acids; in other cases atomic wandering occurs, and αβ-olefine carboxylic acids result (pp. 293, 371) (C. 1906, I. 999; II. 318).

β-Hydroxyacids are produced (1) in the oxidation of primary-secondary and primary-tertiary glycols; (2) (p. 357) by the reduction of β-ketone carboxylic esters (secondary hydroxy-acids); and (3) on boiling βγ- or Δ_2-olefine carboxylic acids with sodium hydroxide. Furthermore, zinc and the esters of the monohalogen fatty acids—*e.g.* bromisobutyric ester—combine with aldehydes (isobutyl aldehyde) to form secondary β-hydroxy-acids, and with ketones to form tertiary β-hydroxy-acids (B. **28**, 2838, 2842; C. 1906, I. 999; II. 318). In these reactions the following stages can be recognized:—

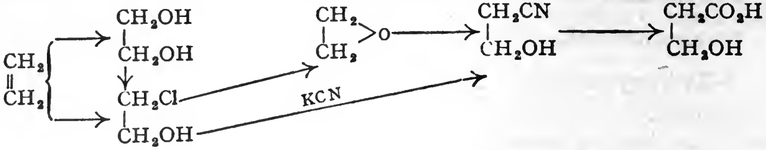


$$\text{I.}\quad \mathrm{CH_2Cl.CO_2R' + Zn = CH_2(ZnCl)COOR'}$$

$$\text{II.}\quad \mathrm{CH_2(ZnCl)CO_2R' + (C_2H_5)_2CO = (C_2H_5)_2C{<}^{CH_2CO_2R'}_{O.Zn.Cl}}$$

$$\text{III.}\quad \mathrm{(C_2H_5)_4C{<}^{CH_2CO_2R'}_{OZnCl} + H_2O = (C_2H_5)_2C{<}^{CH_2CO_2R'}_{OH} + Zn{<}^{OH}_{Cl}}$$

Ethylene Lactic Acid, Hydracrylic Acid [3-Propanol Acid], $\mathrm{CH_2(OH).CH_2.CO_2H}$, is isomeric with *ethylidene lactic acid* or the *lactic acid of fermentation*, and is obtained (1) by the oxidation of trimethylene glycol; (2) from β-iodopropionic acid, or β-chloropropionic acid, with moist silver oxide; (3) from acrylic acid by heating with aqueous sodium hydroxide to 100°; (4) by the saponification of ethylene cyanhydrin with hydrochloric acid. This reaction completes the synthesis of ethylene lactic acid from ethylene:



The free acid forms a non-crystallizable, thick syrup. When heated alone, or when boiled with sulphuric acid (diluted with 1 part H_2O), it loses water and forms acrylic acid (hence the name hydracrylic acid).

Hydriodic acid again changes it to β-iodopropionic acid. It yields oxalic acid and carbon dioxide when oxidized with chromic acid or nitric acid.

The *sodium salt*, $CH_2(OH)CH_2CO_2Na$, m.p. 142–143°, and the *calcium salt*, $(C_3H_5O_3)_2Ca+2H_2O$, m.p. anhydrous 140–150°, when heated above their melting points pass into the corresponding acrylates. The *zinc salt*, $(C_3H_5O_3)_2Zn+4H_2O$, is soluble in water and alcohol, whereas the latter precipitates zinc salts of the isomeric acids. *β-Amyloxypropionic Acid*, $C_5H_{11}OCH_2CH_2COOH$, b.p.$_{20}$ 140°, yields the diamyl-ether of tetramethylene glycol, when its sodium salt is electrolyzed (p. 315) (C. 1905, I. 1698).

β-Hydroxybutyric Acid, [3-Butanol Acid], $CH_3\overset{*}{C}H(OH)CH_2CO_2H$, is formed (1) by the oxidation of *aldol* (p. 338); (2) by the reduction of *acetoacetic ester* (p. 416) with sodium amalgam; (3) from α-propylene chlorhydrin, $CH_3CH(OH)$-CH_2Cl, by the action of KNC and subsequent hydrolysis of the cyanide. It is a thick oil and is volatile in steam. Heat decomposes it into water and crotonic acid, $CH_3.CH:CHCOOH$. Conversely, crotonic ester unites with alcohol in the presence of C_2H_5ONa to form β-ethyoxybutyric ester, $C_2H_5O.CH(CH_3)CH_2$-CO_2R (B. **33**, 3329). The racemic acid is split by means of its quinine salts; the *lævo*-rotatory component $[\alpha]_D=-24{\cdot}9°$ is separated out, and the *dextro*-rotatory component is obtained from the mother liquor. An optically active β-hydroxybutyric acid has been isolated from diabetic urine (B. **18**, R. 451).

β-Hydroxyisobutyric Acid, $HOCH_2CH(CH_3).CO_2H$, is not known.

β-Hydroxy-n-valeric Acid, $CH_3CH_2CH(OH).CH_2CO_2H$ (A. **283**, 74, 94). *α-Methyl β-Hydroxybutyric Acid* $CH_3CH(OH)CH(CH_3)CO_2H$ (A. **250**, 244). *α-Ethyl Hydracrylic Acid*, is a syrup: *ethyl ester*, b.p.$_{13}$ 96°, is obtained from trioxymethylene and α-bromobutyric acid in benzene solution with zinc (C. 1905, II. 45, 540). *β-Hydroxyisovaleric Acid*, $(CH_3)_2C(OH)CH_2.CO_2H$, results when isobutyl formic acid is oxidized with $KMnO_4$ (A. **200**, 273). *α-Dimethyl Hydracrylic Acid, Hydroxypivalic Acid*, $HO.CH_2C(CH_3)_2COOH$, m.p. 124°; *ethyl ester*, b.p.$_{18}$ 86°, is obtained from trioxymethylene, bromisobutyric ester and zinc (C. 1902, I. 643). *Acetoxypivalic chloride* (C. 1908, I. 1531).

β-Hydroxy-n-caproic Acid, $CH_3CH_2CH_2CH(OH)CH_2CO_2H$, is formed on boiling hydrosorbic acid with sodium hydroxide (A. **283**, 124). *α-Ethyl β-Hydroxybutyric Acid*, $CH_3CH(OH)CH(C_2H_5)CO_2H$ (A. **188**, 240). *α-Methyl β-Hydroxyvaleric Acid*, $CH_3CH_2CH(OH)CH(CH_3)CO_2H$ (B. **20**, 1321).

β-Hydroxyisocaproic Acid, $(CH_3)_2CHCH(OH)CH_2CO_2H$ (B. **29**, R. 667). *ββ-Methyl Ethyl Hydracrylic Acid* is obtained by oxidation of methyl ethyl allyl carbinol (C. 1900, I. 1069), *α-Methyl β-Ethyl Hydracrylic Acid* is a syrup. *α-Methyl α-Ethyl Hydracrylic Acid*, m.p. 56°. *α-Propyl Hydracrylic Acid* is a syrup. *α-Isopropyl Hydracrylic Acid*, m.p. 64°. *ααβ-Trimethyl Hydracrylic Acid*, m.p. 31°, b.p.$_{15}$ 148°, is obtained as an ester (method of formation, No. 12, p. 358).

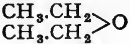
β-Hydroxyisoheptylic Acid, $(CH_3)_2CHCH_2CH(OH)CH_2CO_2H$, m.p. 64° (A. **283**, 143).

β-Methyl Propyl Ethylene Lactic Acid, $(CH_3)(C_3H_7)C(OH)CH_2CO_2H$, is produced in the oxidation of *methyl allyl propyl carbinol* (J. pr. Ch. [2] **23**, 267).

β-Diethyl Ethylene Lactic Acid, $(C_2H_5)_2C(OH)CH_2CO_2H$, results from the oxidation of diethyl allyl carbinol (J. pr. Ch. [2] **23**, 201) (p. 124). *α-Methyl Ethyl β-Hydroxybutyric Acid*, $CH_3CH(OH)C(CH_3)(C_2H_5)CO_2H$ (A. **188**, 266). *Tetramethyl Ethylene Lactic Acid*, $(CH_3)_2C(OH)C(CH_3)_2CO_2H$, m.p. 152°, is prepared from acetone bromisobutyric ester and zinc. It yields CO_2 and dimethyl isopropyl carbinol when heated. The ester and P_2O_5 yield dimethyl isopropenyl acetic acid (B. **28**, 2829; C. 1906, I. 909). *α-Dimethyl β-Ethyl Hydracrylic Acid*, $C_2H_5CH(OH)C(CH_3)_2COOH$, m.p. 103° (C. 1901, I. 1196). *β-Hydroxyiso-octylic Acid*, $(CH_3)_2CHCH_2CH_2CH(OH)CH_2CO_2H$, m.p. 36° (A. **283**, 287).

α-Methyl Propyl β-Hydroxybutyric Acid, $CH_3CH(OH)C(CH_3)(C_3H_7)CO_2H$ (A. **226**, 288). *α-Diethyl β-Hydroxybutyric Acid*, $CH_3CH(OH)C(C_2H_5)_2CO_2H$ (A. **201**, 65; **266**, 98). *α-Dimethyl β-Isopropyl Ethylene Lactic Acid*, $(CH_3)_2CH.CH(OH).C(CH_3)_2.CO_2H$, m.p. 92° (B. **28**, 2843), is obtained also by oxidation of the corresponding glycol (p. 316) or aldol (p. 373) (C. 1902, I. 461).

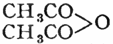
The γ- and δ-Hydroxy-acids and their Cyclic Esters, the γ- and δ-Lactones.—The γ- and δ-hydroxy-acids are distinguished from the α- and β-hydroxy-acids* by the fact mentioned (p. 362) that they are capable of forming simple cyclic esters, when the carboxyl group enters into reaction with the alcoholic hydroxyl group. This is a reaction that is accelerated by mineral acids in the case of the formation of the ordinary fatty acid esters. The cyclic esters of the γ- and δ-hydroxy-acids are called **γ-Lactones** and **δ-Lactones**. In the first there is a chain of four, in the second a chain of five carbon atoms closed by oxygen. They sustain the same relation to the oxides of the γ- and δ-glycols, and to the *anhydrides of the γ- and δ-dicarboxylic acids*, that the open carboxylic esters bear to the ethers of the alcohols and fatty acid anhydrides. Suppose, for example, that a hydrogen atom has been removed from each methyl group in the formulæ of ethyl ether, acetic ethyl ester and acetic anhydride, and the methylene esidues are then joined to each other, we then arrive at the formulæ of tetramethylene oxide, γ-butyrolactone and succinic anhydride. The following scheme represents these relations:


$\begin{matrix}CH_3.CH_2\\CH_3.CH_2\end{matrix}>O$

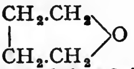
Ethyl Ether.


$\begin{matrix}CH_3CO\\CH_3.CH_2\end{matrix}>O$

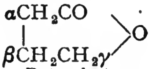
Acetic Ethyl Ester.


$\begin{matrix}CH_3CO\\CH_3CO\end{matrix}>O$

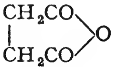
Acetic Anhydride.


$\begin{matrix}CH_2.CH_2\\|\\CH_2.CH_2\end{matrix}>O$

Tetramethylene Oxide.


$\begin{matrix}\alpha CH_2CO\\|\\\beta CH_2CH_2\gamma\end{matrix}>O$

γ-Butyrolactone.


$\begin{matrix}CH_2CO\\|\\CH_2CO\end{matrix}>O$

Succinic Anhydride.

This lactone formation occurs more or less easily, depending upon he constitution of the γ-hydroxy-acids. The very same causes which nfluence the anhydride formation with saturated and unsaturated icarboxylic acids (*q.v.*), exert their power with the γ-hydroxy-acids. t has been seen "that increasing magnitude or number of hydroarbon residues in the carbon chains closed by oxygen favours the intramolecular splitting-off of water among the γ-hydroxy-acids" (B. **24**, 237). When the γ-hydroxy-acids are separated from their salts by mineral acids they break down, especially on warming, almost

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* The lactone of a β-hydroxy-acid is exemplified by asym.-dimethyl malic ctone (*q.v.*).

immediately into water and lactones. It is only when the latter are boiled with alkali carbonates that they are converted into salts of the hydroxy-acids. This is more readily accomplished through the agency of the alkali hydroxides. The γ-lactones are characterized by great stability, being only partially converted into hydroxy-acids by water, after protracted boiling, whereas those of the δ-variety gradually absorb water at the ordinary temperature and soon react acid (B. **16**, 373).

History.—The first (1873) discovered aliphatic lactone was butyrolactone, obtained by *Saytzeff*, who, however, regarded it as the dialdehyde of succinic acid. *Erlenmeyer*, Sr. (1880), expressed the opinion that lactones could only exist when they contained the group C—C—C—COO, which is present, as is well known, in the anhydrides of succinic acid (B. **13**, 305). Almost immediately afterwards *J. Bredt* demonstrated that isocaprolactone, from pyroterebic acid, was in fact a γ-lactone (B. **13**, 748). *Fittig*, as the result of a series of excellent investigations, established the genetic relations of the lactones to the hydroxy-acids and unsaturated acids, and taught how this class of bodies could be produced by new methods. *E. Fischer* has shown that polyhydroxylactones play an especially important rôle in the synthesis of the various varieties of sugar.

The general methods of formation of the *γ-hydroxycarboxylic acids* and their cyclic esters—the *γ-lactones:*

(1) By the reduction of the *γ-ketone carboxylic acids* with sodium amalgam:

$$CH_3CO.CH_2CH_2COOH + 2H = CH_3CH(OH).CH_2CH_2CO_2H.$$

Lævulinic Acid. γ-Hydroxyvaleric Acid.

(2) From the *γ-halogen fatty acids:* (*a*) by distillation, when the lactones are immediately produced:

$$ClCH_2CH_2CH_2CO_2H \longrightarrow CH_2CH_2CH_2COO + HCl;$$

(*b*) by boiling them with water, or with alkali hydroxides, or carbonates. In the latter case γ-lactones are even produced in the cold.

(3) From *unsaturated acids* in which the double union occurs in the βγ- or γδ-position, that is, from the Δ²-(βγ)- or Δ³-(γδ)- unsaturated acids:

(*a*) by distillation;

(*b*) by digestion with hydrobromic acid, when an addition and separation of hydrogen bromide occur;

(*c*) by digestion with dilute sulphuric acid (B. **16**, 373; **18**, R. 229; **29**, 1857):

$$\overset{\delta}{C}H_2{=}\overset{\gamma}{C}H\overset{\beta}{C}H_2\overset{\alpha}{C}H_2CO_2H \longrightarrow CH_3CHCH_2CH_2COO$$

Allyl Acetic Acid. γ-Valerolactone.

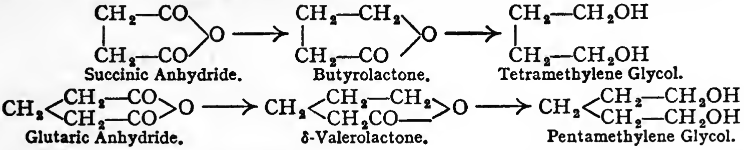
(4) By the decomposition of *γ-lactone carboxylic acids* into γ-lactones and CO₂, by distillation, whereby the isomeric unsaturated acids are also produced (pp. 292, 300):

$$\begin{matrix}CH_3\\CH_3\end{matrix}{>}C.CH(COOH).CH_2COO \longrightarrow \begin{matrix}CH_3\\CH_3\end{matrix}{>}C.CH_2.CH_2.COO + CO_2.$$

Terebic Acid. Isocaprolactone.

By similar reactions lactones can be formed by decomposition of the condensation product of glycol halogenhydrin (p. 319), (*a*) with sodium acetoacetic ester, and (*b*) sodium malonic ester.

(5) Reduction of the derivatives of dicarboxylic acids leads to the formation of glycols (conformably with method of formation 5*b*, p. 310). Alcohol acids are formed as intermediate products during reduction; in the cases of esters, chlorides, or anhydrides of the succinic and glutaric acid series, reduction with sodium or aluminium amalgam, or with sodium and alcohol, gives rise to a 5–50 per cent. yield of γ- and δ-hydroxy-acids and γ- and δ-lactones respectively.



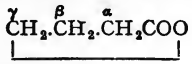
Since it is possible to prepare the half-nitrile of the higher dicarboxylic acids by means of potassium cyanide, and to convert these again into lactones, these reactions constitute a method for the synthesis of higher lactones out of the lower members. Asym.-alkyl succinic acids and asym.-alkyl glutaric acids when reduced yield in the main the two possible lactones (B. **36**, 1200; C. 1904, I. 925; 1905, II. 755).

Nucleus-synthetic Methods of Formation:

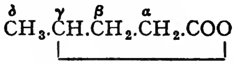
(6) The action of zinc alkyls on the chlorides of dibasic acids, or of magnesium alkyl halides on γ-ketonic acid (C. 1902, II. 1359).

(7) KNC on γ-halohydrins, and subsequent saponification of the resulting nitriles.

Nomenclature.—γ-Lactones may be viewed as α-, β-, and γ-alkyl substitution products of butyrolactone, and may be named accordingly; thus, γ-methyl butyrolactone for valerolactone:



$$\overset{\gamma}{C}H_2.\overset{\beta}{C}H_2.\overset{\alpha}{C}H_2COO$$



$$\overset{\delta}{C}H_3.\overset{\gamma}{C}H.\overset{\beta}{C}H_2.\overset{\alpha}{C}H_2.COO$$

The "Geneva names" terminate in "olide"; thus, *butyrolactone* =[Butanolide]; *valerolactone*=[1,4-pentanolide].

Properties of the γ- and δ-Lactones. They are usually liquid bodies, easily soluble in water, alcohol, and ether. They possess a neutral reaction, and a faintly aromatic odour, and can be distilled without decomposition. The alkali carbonates precipitate them from their aqueous solution in the form of oils.

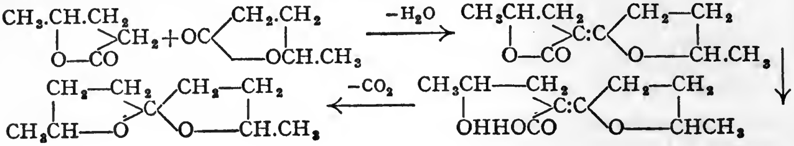
Reactions.—(1) They are partially converted into the corresponding hydroxy-acids when boiled with water. A state of equilibrium arises here, which is much influenced by the number of alcohol radicals contained in the γ-lactones. (2) The lactones are changed with difficulty by the alkali carbonates into salts of the corresponding hydroxy-acids (B. **25**, R. 845), whereas the alkali hydroxides and barium hydroxide solution effect this more readily. (3) Many γ-lactones combine with the halogen acids, forming the corresponding γ-halogen fatty acids; others do not do this. In the latter the lactone union is easily severed on allowing hydrochloric or hydrobromic acid to act on the lactones in the presence of alcohol. Then the *alkyl ethers* of the corresponding γ-chloro- and γ-bromo-fatty acids are formed (B. **16**, 513). Lactones are converted into the esters of hydroxy-acids by heating them with sulphuric acid in alcoholic solution (B. **33**, 860).

(4) The γ-lactones unite with ammonia, but there is no separation of water (p. 378). Similarly, with hydrazine, which gives characteristic crystalline addition-products, easily split up into hydrazine and lactone (C. 1905, I. 1221).

(5) Sodium and alcohol reduce the lactones to glycols.

(6) Potassium cyanide unites with the formation of potassium salts of the nitrile-carboxylic acids.

(7) The lactones condense under the influence of sodium and sodium alcoholate to compounds which give up water when treated with acids to form substances composed of two lactone residues. When boiled with bases, these bodies are converted to hydroxycarboxylic acids, which split off carbon dioxide, forming *oxetones* (*q.v.*), derivatives of dioxyketones:



γ-Lactones.

Butyrolactone [Butanolide], $CH_2.CH_2.CH_2.COO$, b.p. 206°, has been obtained (1) by allowing sodium amalgam and glacial acetic acid to act on succinyl chloride in ethereal solution (A. **171,** 261; B. **29,** 1192); (2) from β-formyl propionic acid (p. 402) by reduction; (3) from butyrolactone carboxylic acid (*q.v.*), by the splitting-off of CO_2 (B. **16,** 2592); (4) by the distillation of γ-chlorobutyric acid (B. **19,** R. 13); (5) from oxethyl acetoacetic ester (the reaction product of ethylene chlorhydrin and acetoacetic ester) by decomposing it with barium hydroxide (B. **18,** R. 26); (6) by treating γ-phenyl hydroxybutyric acid with hydrobromic acid (B. **29,** R. 286).

Lactones, $C_5H_8O_2$; **γ-Valerolactone,** *γ-Methyl Butyrolactone,* [1,4-Pentanolide], $CH_3.CH.CH_2.CH_2.COO$, b.p. 206°, occurs in crude wood vinegar, and may be prepared (1) by the reduction of lævulinic acid, $CH_3CO.CH_2CH_2CO_2H$ (A. **208,** 104); (2) by boiling allyl acetic acid with dilute sulphuric acid; (3) when γ-bromovaleric acid is boiled with water; (4) on heating γ-hydroxypropyl malonic lactone to 220° C. (A. **216,** 56); (5) and in small quantities when *methyl paraconic acid* is distilled (A. **255,** 25). Dilute nitric acid oxidizes γ-valerolactone to ethylene succinic acid, whilst HI converts it into n-valeric acid.

α-Methyl Butyrolactone, $CH_2CH_2CH(CH_3)COO$, b.p. 201°, is obtained from pyrotartaric chloride or anhydride by reduction (B. **28,** 10; **29,** 1194; C. 1905, II. 755).

Lactones: $C_6H_{10}O_2$.

Caprolactones. *γ-Ethyl Butyrolactone, γ-n-Caprolactone,* [1,4-Hexanolide], $CH_3.CH_2CHCH_2CH_2COO$, b.p. 220°, is formed by the general methods 2, 3, and 4. It also appears in the reduction of gluconic acid, metasaccharic acid and galactonic acid by hydriodic acid (B. **17,** 1300; **18,** 642, 1555).

α-Ethyl Butyrolactone, b.p. 219°, is prepared from ethyl succinic anhydride and from α-ethyl α-ethoxyacetoacetic ester.

βγ-Dimethyl Butyrolactone, b.p. 209°, is obtained from β-acetobutyric acid.

αα-Dimethyl Butyrolactone, b.p. 202°, is formed, together with its isomer *ββ-Dimethyl Butyrolactone,* by reduction of unsym.-dimethyl succinic ester as anhydride (C. 1904, I. 925; II. 587).

Isocaprolactone, *γ-Dimethyl Butyrolactone,* $(CH_3)_2CCH_2CH_2COO$, m.p. 7°, b.p. 207°, is produced together with pyroterebic acid in the distillation of terebic acid. (See general method 4, p. 372.) Pyroterebic acid itself passes on long boiling into isocaprolactone. It can also be obtained from isobutyric aldehyde, malonic acid and acetic anhydride (B. **29,** R. 667).

Lactones: $C_7H_{12}O_2$. **γ-n-Propyl Butyrolactone,** γ-n-*Heptolactone*,, CH_3CH_2-$CH_2CHCH_2CH_2COO$, b.p. 235°, is obtained from γ-bromœnanthic acid, from n-propyl paraconic acid, and from dextrose carboxylic acid, as well as from galactose carboxylic acid on treatment with hydriodic acid (B. **21**, 918). *γ-Isopropyl Butyrolactone*, $(CH_3)_2CH.CHCH_2CH_2COO$, b.p. 224°, is formed from isopropyl paraconic acid. α- and *β-Isopropyl Butyrolactone* are obtained from isopropyl succinic anhydride. *ααγ-Trimethyl Butyrolactone*, *α-Dimethyl Valero-γ-lactone*, $CH_3.CH.CH_2C(CH_3)_2COO$, m.p. 52°, b.p.$_{18}$ 86°, may be obtained from α-dimethyl lævulinic acid (mesitonic acid (*q.v.*) and from ααγ-trimethyl vinyl acetic acid (C. 1904, I. 720). *αγγ-Trimethyl Butyrolactone*, m.p. 50°, is prepared from αγγ-trimethyl β-hydroxybutyric acid (comp. p. 369) (C. 1897, II. 572). ***α-Ethyl γ-Methyl Butyrolactone***, b.p. 219°, is prepared from α-ethyl β-acetopropionic acid and ethyl allyl acetic acid, mode of formation, No. 3 (B. **29**, 1857). ***γγ-Ethyl Methyl Butyrolactone***, b.p.$_{18}$ 106°, is obtained from lævulinic ester and ethyl magnesium halides.

Lactones: $C_8H_{14}O_2$.

γ-Isobutyl Butyrolactone is prepared from isobutyl paraconic acid. *α-Propyl γ-Methyl Butyrolactone*, b.p. 233°. *α-Isopropyl γ-Methyl Butyrolactone*, b.p. 224° (B. **29**, 1857, 2001). *α-Ethyl βγ-Dimethyl Butyrolactone*, b.p. 227°, is obtained from α-ethyl β-methyl β-acetopropionic acid. *γ-Diethyl Butyrolactone*, b.p. 228–233°, is prepared from succinyl chloride and zinc ethyl.

δ-Lactones are obtained from the corresponding δ-halogen carboxylic acids by distillation, or from the δ-keto-carboxylic acids (p. 424), as well as from glutaric esters or anhydride (p. 501) by reduction. *δ-Valerolactone*, $CH_2CH_2CH_2CH_2COO$, b.p.$_{14}$ 114°, changes spontaneously into a *polymer*, m.p. 48°, which is decomposed by alkali into δ-hydroxyvaleric acid, as is also the simple lactone (B. **26**, 2574; **36**, 1200; A. **319**, 367). *δ-Methyl δ-Valerolactone*, *δ-Caprolactone*, $C_6H_{10}O_2$, m.p. 13°, b.p. 275°. α- or *γ-Methyl δ-Valerolactone* (B. **36**, 1201). *αα-Dimethyl δ-Valerolactone*, $C_7H_{12}O_2$, b.p.$_{15}$ 105°. *ββ-Dimethyl δ-Valerolactone*, m.p. 30°, b.p. 225° (C. 1905, II. 753). *γ-Ethyl δ-Methyl δ-Valerolactone*, b.p. 255° (A. **216**, 127; **268**, 117).

ε-Hydroxy-carboxylic Acids and hydroxy-acids containing a still *more remote position* of the alcoholic CH-group show no further tendency to lactone-formation. They seem rather to split off water like the β-hydroxy-acids, since olefine carboxylic acids are obtained from the corresponding amino-carboxylic acids with nitrous acid, together with or instead of the hydroxy-acids (A. **343**, 44).

However, **ε-Lactones** have been obtained by the oxidation of certain terpene ketones with permonosulphuric acid (*Caro's* acid). *β-Methyl ε-Isopropyl ε-Caprolactone*, $C_3H_7CHCH_2CH_2CH(CH_3)CH_2COO$, b.p.$_{17}$ 129°, m.p. 4·8° and 47°, according to the geometrical isomer. It is obtained from *menthone* (Vol. II.). The two isomers yield *hydroxy-acids*, one fluid and the other, m.p. 65°; but only one ε-keto-acid is obtained by oxidation. *Tetrahydrocarvone* (Vol. II.) similarly treated yields *β-Isopropyl ε-Methyl ε-Caprolactone*, b.p.$_{21}$ 156°. *Methyl Cyclohexanone* (Vol. II.) gives rise to a lactone, which, on breaking down, passes into *methyl ε-hydroxycaproic acid*. *Suberone* (Vol. II.) appears to give a *ζ-lactone* which passes into *ζ-Hydroxyœnanthylic acid*, $HOCH_2[CH_2]_5COOH$, on decomposition (B. **33**, 858).

ε-Hydroxycaproic Acid, $HO[CH_2]_5.COOH$; *phenyl ether*, $C_6H_5O[CH_2]_5COOH$, m.p. 71°, is obtained by adding potassium cyanide to ε-chloramyl phenyl ether and hydrolyzing the resulting nitrile (B. **38**, 965).

10-*Hydroxyundecylic Acid*, $HOCH_2[CH_2]_9COOH$, m.p. 70°, is obtained from ω-bromundecylic acid and silver oxide. Oxidation converts it into nonane dicarboxylic acid (C. 1901, II. 1043). 9-*Hydroxystearic Acid*, $C_8H_{17}CH(OH)$-$[CH_2]_8COOH$, m.p. 83°, is produced from oleic acid through iodo- or sulphostearic acid (p. 377). If oleic acid is heated with zinc chloride it is converted into the so-called *stearolactone*, $C_{18}H_{32}O_2$, probably *γ-tetradecyl butyrolactone* (C. 1903, I. 1404). 13-*Hydroxybehenic Acid*, $C_8H_{17}.CH(OH)C_{12}H_{24}COOH$, m.p. 90° (C. 1908, I. 2019).

Sulphur Derivatives of the Hydroxy-acids:

Only the mercaptan carboxylic acids and their reaction products will be considered here. These are acids which at the same time possess the nature of a mercaptan. They are obtained as oils, with a disagreeable odour, and are miscible with water, alcohol, and ether.

1. **Mercaptan Carboxylic Acids** are prepared (1) from halogen-fatty acids and KSH; (2) the xanthogen-fatty acids resulting from potassium xanthogenate (*q.v.*) and chloro-fatty acids, are decomposed by ammonia into mercaptan-carboxylic acid and xanthogen amide (B. **39**, 732; A. **348**, 120):

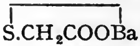
$$ClCH_2COOK+KSH=HSCH_2COOK+KCl$$

$$C_2H_5OCS.SCH(CH_3)COONH_4+NH_3=HSCH(CH_3)COONH_4+C_2H_5OCS.NH_2.$$

(3) The mercaptan- or thio-carboxylic acids are easily oxidized to *disulphides*, such as $(HOOCCH_2)_2S_2$, which may also be prepared directly from halogen-fatty acids and potassium polysulphides; on reduction, the mercaptan carboxylic acids are re-formed (C. 1907, I. 856; 1908, I. 1221).

These bodies tend to form complex salts.

Thioglycollic Acid, [Ethanethiol Acid], $HS.CH_2COOH$, m.p. —16·5°, b.p.$_{13}$ 103°, is obtained from monochloracetic acid and potassium hydrogen sulphide; and from thiohydantoïn, when heated with alkalis (A. **207**, 124). On adding ferric chloride to its solution an indigo-blue coloration is obtained. It is a dibasic acid. (Conductivity, B. **39**, 736.) The *barium salt*, $\overbrace{S.CH_2COOBa}+3H_2O$, dissolves with difficulty in water; *ethyl ester*, b.p.$_{17}$ 55°; *amide*, m.p. 52°. On being heated, it yields the thioglycollic acid *thioglycollide* $(SCH_2CO)_x$, m.p. about 80°.



a-Thiolactic Acid, $CH_3CH(SH)CO_2H$, m.p. 10°, b.p.$_{14}$ 99°, is prepared from pyroracemic acid (p. 407) and sulphuretted hydrogen; also, together with *cysteïne*, α-amino-β-thiopropionic acid (*q.v.*) (C. 1903, I. 15), from horn (keratin) by decomposition with hydrochloric acid. *β-Thiolactic Acid*, $HS.CH_2CH_2CO_2H$, m.p. 16·8°, b.p.$_{15}$ 11°, $D_{20}=1·218$.

α-Thiobutyric acid, b.p.$_{19}$ 118–122°; *α-Thioisobutyric acid*, m.p. about 47°, b.p.$_{15}$ 102°.

The first product of reaction of KSH and γ-chlorobutyronitrile is probably *Dithiobutyrolactone*, which loses H_2S and condenses further to the red coloured *Trithiodibutyrolactone*, $C_8H_{10}S_3$, m.p. 116°. Its structure is probably analogous to that of the condensation production of the lactone with sodium ethoxide (p. 374) (B. **34**, 3387).

2. **α-Alkyl Sulphide Carboxylic Acids** are obtained from the interaction of α-halogen fatty acids and sodium mercaptides. *Ethyl Sulphide Acetic Acid*, $C_2H_5S.CH_2COOH$, m.p. $-8·7°$, b.p.$_{11}$ 118°; D_{20} 1·1518 (B. **40**, 2588).

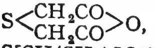
3. **α-Mercaptal Carboxylic Acids** result from the action of α-thio-acids on aldehydes. *Ethylidene Dithioglycollic Acid*, $CH_3CH{:}(SCH_2.COOH)_2$, m.p. 107°.

4. **α-Mercaptol Carboxylic Acids** result from α-thio-acids and ketones in the presence of zinc chloride or HCl.

Dimethyl Methylene Dithioglycollic Acid, $(CH_3)_2C{:}(SCH_2COOH)_2$, m.p. 126°.

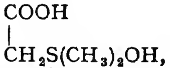
5. **α-Sulphide Dicarboxylic Acids** are produced when K_2S acts on α-halogen fatty acids.

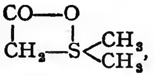
Thiodiglycollic Acid, $S(CH_2CO_2H)_2$, m.p. 129°, corresponds in composition with diglycollic acid (p. 367), and under like conditions forms a cyclic anhydride, which is both a sulphide and a carboxylic anhydride. *Thiodiglycollic Anhydride*, $S{<}\begin{smallmatrix}CH_2CO\\CH_2CO\end{smallmatrix}{>}O$, m.p. 102°, b.p.$_{10}$ 158° (B. **27**, 3059). *α-Thiodilactylic Acid*, $S[CH(CH_3)CO_2H]_2$, m.p. 125°. *γ-Thiodibutyric Acid*, m.p. 99° (B. **25**, 3040). unsym.-*Sulphide Dicarboxylic Acids* are obtained from the disodium salts of the mercaptan carboxylic acids and sodium halogen fatty acids in aqueous solution (B. **29**, 1139).



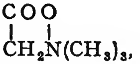
6. **Disulphide Dicarboxylic Acids** are readily produced in the oxidation of the mercaptan carboxylic acids in the air, or with ferric chloride or iodine. *Dithiodiglycollic Acid*, $S_2(CH_2CO_2H)_2$, m.p. 100°. *α-Dithiodilactic Acid*, $S_2[CH(CH_3).CO_2H]_2$, m.p. 141°. *β-Dithiodipropionic Acid*, $S_2(CH_2CH_2COOH)_2$, m.p.

155° (A. **339**, 351). *Trisulphide Acetic Acid*, $S_3(CH_2COOH)_2$, m.p. 124°. *Tetrasulphide Acetic Acid*, $S_4(CH_2COOH)_2$, m.p. 113° (A. **359**, 81).

7. **Hydroxysulphine Carboxylic Acids.**—The free bodies—*e.g.*  $\begin{array}{l}COOH\\ |\\ CH_2S(CH_3)_2OH\end{array}$, are unstable. They split off water and yield *cyclic sulphinates*, which are constituted similarly to the cyclic ammonium compounds, and are called *thetines*. This name, from the contraction of *thio* and *betaïne*, is intended to express the analogy between their derivatives and betaine (B. **7**, 695; **25**, 2450; **26**, R. 409):



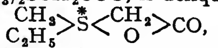
$\begin{array}{ll}CO—O & \\ | \quad\;\; | & \\ CH_2—S\!<\!\begin{array}{l}CH_3\\ CH_3\end{array}\end{array}$, *Dimethyl Thetine*;

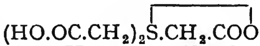


$\begin{array}{l}COO\\ | \quad |\\ CH_2N(CH_3)_3\end{array}$, *betaïne* (p. 330).

The thetines are feeble bases. Their hydrobromides are produced when methyl sulphide, ethyl sulphide, and sodium thiodiglycollate are brought into action with α-halogen fatty acids—*e.g.* chloracetic acid and α-bromopropionic acid.

Dimethyl Thetine,  $(CH_3)_2\overline{SCH_2COO}$, is deliquescent.

Methyl Ethyl Thetine,  $\begin{array}{l}CH_3\\ C_2H_5\end{array}\!>\!\overset{*}{S}\!<\!\begin{array}{l}CH_2\\ O\end{array}\!>\!CO$, contains an *asymmetric sulphur atom*, and is resolved into its two forms by means of its salts with camphor-sulphonic acid and bromocamphor-sulphonic acid: d-*chloroplatinate*, $[\alpha]_D = +4.5°$ (C. 1900, II. 623).

Dimethyl Thetine Dicarboxylic Acid,  $(HO.OC.CH_2)_2\overline{S.CH_2.COO}$, m.p. 157–158°. *Diethylene Disulphide Thetine* (C. 1899, II. 1105). Further compounds, B. **33**, 823.

Selenetines, see B. **27**, R. 801.

8. **Sulphone Carboxylic Acids** are produced by the action of alkyl sulphinates on esters of halogen fatty acids, and resemble the ketone carboxylic acids (*q.v.*). *Ethyl Sulphone Acetic Acid*, $C_2H_5SO_2.CH_2CO_2H$. *Ethyl Sulphone Propionic Acid*, $C_2H_5SO_2.CH_2CH_2CO_2H$ (B. **21**, 89, 992). By oxidizing the sulphide, corresponding with the sulphones with $KMnO_4$, there are obtained: *Sulphone Diacetic Acid*, $O_2S(CH_2CO_2H)_2$, m.p. 182°. *α-Sulphone Dipropionic Acid*, $O_2S[CH(CH_3).CO_2H]_2$, m.p. 155° (B. **18**, 3241). Sulphone diacetic acid resembles acetoacetic ester in many respects. For mixed sulphone-di-fatty acids see B. **29**, 1141.

9. **α-Sulphocarboxylic Acids.** The sulpho-acids of the fatty acids are produced by methods similar to those employed with the alkyl sulphonic acids:

(1) By the action of sulphur trioxide on the fatty acids, or by acting with fuming sulphuric acid on the anhydrides, nitriles, or amides of the acids (J. pr. Ch. [2] **73**, 538; C. 1905, I. 1309).

(2) By heating concentrated aqueous solutions of the salts of the mono-substituted fatty acids with alkali sulphites.

(3) By the addition of alkali sulphites to unsaturated acids (B. **18**, 483).

(4) By oxidizing the thio-acids corresponding to the hydroxy-acids with nitric acid.

(5) Upon oxidizing glycol sulphonic acids, *e.g.* isethionic acid, with nitric acid.

These sulpho-acids are dibasic acids, corresponding with malonic acid in their chemical behaviour. They are, however, more stable towards heat, alkalis, and acids.

Sulpho-acetic Acid, $HO_3S.CH_2COOH$, is prepared by decomposing *acetone trisulphonic acid* by means of alkali; methionic acid is formed at the same time (p. 210) (C. 1902, I. 101). *Chlorosulphonic Acetyl Chloride*, $ClO_2S.CH_2COCl$, b.p.$_{150}$ 130–135°, is converted into thioglycollic acid by reduction. *Ethyl Sulphonic Ethyl Acetic Ester*, $C_2H_5O_3S.CH_2COOC_2H_5$, is obtained as an oil, volatile with partial decomposition. The hydrogen atoms in the CH_2-group can be replaced by alkyl groups, comparable to the esters and amides of methionic acid (p. 210), to form acetoacetic ester (p. 410) and to malonic ester (B. **21**, 1550).

Sulpho-isobutyric Acid, $HO_3S.C(CH_3)_2COOH$, is formed by the interaction of isobutyryl chloride or anhydride and concentrated sulphuric acid. The *barium salt* ($+3H_2O$) is less easily soluble in hot water than in cold; *dimethyl ester*, m.p. 4°, b.p. 78–82°; *dichloride*, m.p. 10°, b.p. 55° (C. 1905, I. 1309).

NITROGEN DERIVATIVES OF THE HYDROXY-ACIDS

The following classes of nitrogen compounds are derived from the α-hydroxy-acids: (1) Amides. (2) Imidohydrins. (3) Hydrazides. (4) Azides. (5) Nitriles. (6) Nitro-acids. (7) Nitroso-acids. (8) Hydroxylamino-acids. (9) Amidoxy-acids. (10) Amino-acids. (11) Nitramino-acids. (12) Isonitramino-acids. (13*a*) Hydrazine acids. (13*b*) Hydrazo-acids. (14) Azo-acids.

The α-amino-acids and their derivatives are of especial interest from the physiological standpoint, as being decomposition products of the proteïns.

1. **Hydroxyamides.**—The α-hydroxyamides are produced (1) by treating (*a*) alkyl esters and (*b*) cyclic double esters of the lactides with ammonia. (2) From the α-hydroxynitriles by the absorption of water in the presence of a mineral acid, particularly sulphuric acid. They behave like the fatty acid amides.

Glycollamide, $HOCH_2CO.NH_2$, m.p. 120°, is obtained from polyglycollide, or from acid ammonium tartronate when heated to 150°. It possesses a sweet taste.

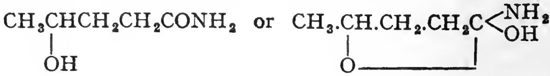
Lactamide, $CH_3CH(OH).CONH_2$, m.p. 74°.

α-Hydroxycaprylamide, $CH_3(CH_2)_5CH(OH)CONH_2$, m.p. 150° (A. **177**, 108). Diglycollic acid yields two amides and a cyclic imide:

Diglycollamic Acid, $NH_2COCH_2OCH_2CO_2H$, m.p. 135°.

Diglycollamide, $O(CH_2CONH_2)_2$, breaks down when heated into ammonia and *diglycollimide,* $O<\begin{matrix}CH_2.CO\\CH_2.CO\end{matrix}>NH$, m.p. 142°. It behaves like the imides of the dicarboxylic acids, *e.g.* succinimide (*q.v.*) and *n*-glutarimide.

The readily decomposable additive products, arising from ammonia and the γ-lactones (A. **256**, 147), are regarded as being as γ-hydroxy-acid amides. Yet they are said to have a constitution similar to aldehyde-ammonia (A. **259**, 143). The additive product from ammonia and γ-valerolactone may have one of the following formulæ:



$$\underset{\displaystyle OH}{CH_3\overset{}{C}H}CH_2CH_2CONH_2 \quad \text{or} \quad CH_3.CH.CH_2.CH_2C<\begin{matrix}NH_2\\OH\end{matrix}. \ (\text{CH bonded to O, O bonded to C})$$

The addition products of hydrazine and γ-lactones behave similarly: *Hydrazine γ-Valerolactone,* $\overline{O.CH(CH_3)CH_2CH_2C}(OH)$, m.p. 62°, also easily dissociates into hydrazine and lactone (C. 1905, I. 1221).

2. **α-Hydroxy-imidohydrins.** The *imido-ethers* of the α-hydroxy-acids, whose salts are prepared in the ordinary way from nitriles by means of alcohols and HCl (p. 281), are hydrolyzed when in the free state by water, into the *imidohydrins.* These are isomeric with the corresponding amides, although they appear to consist of a double molecule and behave as electrolytes in aqueous solution (B. **30**, 998; **34**, 3142).

Glycoliminohydrin, $\left(HOCH_2C<\begin{matrix}NH\\OH\end{matrix}\right)_2$, m.p. 160°; *Lactimidohydrin,* m.p. 135°; *Hydroxyisobutyl Imidohydrin,* m.p. 173°.

3. **Hydrazides of the Hydroxy-acids:** *Glycol Hydrazide,* $HOCH_2CO.NHNH_2$, m.p. 93°, has been prepared from benzoyl or oxalyl glycollic ester and hydrazine hydrate (J. pr. Ch. [2], **51**, 365).

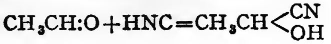
4. **Azides of the Hydroxy-acids:** *Glycol Azide,* $HOCH_2.CON_3$, is formed when sodium nitrite acts on the hydrochloride of glycol hydrazide. It crystallizes from ether (J. pr. Ch. [2], **52**, 225).

5. Nitriles of the Hydroxy-acids.

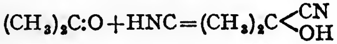
The nitriles of the α-hydroxy-acids are the additive products obtained from hydrocyanic acid and the aldehydes, and ketones.

The *aldehydes* yield *nitriles of secondary hydroxy-acids.* Formaldehyde is an exception in this respect, for it gives rise to the nitrile of a primary hydroxy-acid,—glycollic acid.

The *ketones* yield *nitriles of tertiary hydroxy-acids.*



$$CH_3CH{:}O+HNC=CH_3CH<^{CN}_{OH}$$ Nitrile of lactic acid (p. 362).



$$(CH_3)_2C{:}O+HNC=(CH_3)_2C<^{CN}_{OH}$$ Nitrile of acetonic acid (p. 365).

These nitriles of the α-hydroxy-acids have been called the cyanhydrins of the aldehydes and ketones. They result by the reaction of the aldehyde and ketone *bisulphite* compounds (pp. 207, 225) with potassium cyanide (B. **38**, 214 ; **39**, 1224, 1856).

Many of the anhydrous substances boil without decomposition, especially under reduced pressure ; but many break down upon the evaporation of their aqueous solution, and alkalis resolve them into their components. The nitriles of the α-hydroxy-acids, on the other hand, under the influence of mineral acids, *e.g.* hydrochloric acid and sulphuric acid, first take up one molecule of water and change to α-hydroxy-acid amides (see above), then a second molecule of water, and form the ammonium salts of the α-hydroxy-acids, which are immediately decomposed by mineral acids (p. 277).

When heated with P_2O_5 they change into olefine carboxylic nitriles ; with PCl_5 into chloroparaffin carboxylic nitriles (C. 1898, II. 22, 662). Ammonia causes the formation of water and amino-nitriles (p. 381). Cyanacetic ester and the α-hydroxy-acid nitriles produce water and derivatives of αβ-dicyanopropionic acids, $R_2C(CN).CH(CN)CO_2C_2H_5$ (C. 1906, II. 1561).

Aldehyde Cyanhydrins.

Glycollic Acid Nitrile [Ethanol Nitrile], $HO.CH_2CN$, b.p. 183° with decomposition, b.p.$_{28}$ 103° (J. pr. Ch. [2] **65**, 189). *Acyl Glycollic Nitriles* are prepared from chloracetic nitrile with the sodium or potassium salts of the fatty acids (C. 1904, II. 1377). *Formyl Gycollic Acid Nitrile*, HCO_2CH_2CN, b.p. 173°, and *Acetyl Glycollic Acid Nitrile*, b.p. 180°, result also from glycol aldoxime and acetic anhydride, and are decomposed by ammoniacal silver oxide into AgCN and formaldehyde (C. 1900, II. 313). *Ethers* of glycollic nitrile are prepared from chloromethyl alkyl ethers and silver, mercury, or copper cyanide :

$$2CH_3OCH_2Cl+Hg(CN)_2=2CH_3OCH_2CN+HgCl_2.$$

Methoxyacetonitrile, b.p. 120° ; *Ethoxyacetonitrile*, b.p. 135° (C. 1907, I. 400, 871).

Ethylidene Lactic Acid Nitrile, Aldehyde Cyanhydrin, $CH_3CH(OH)CN$, b.p.$_{30}$ 102° ; *ethyl ether*, $CH_3CH(OC_2H_5)CN$, b.p. 88°, is prepared from cyanogen chloride and ethyl ether (B. **28**, R. 15) ; *acetyl ester*, $CH_3CH(OCOCH_3)CN$, b.p. 169° (B. **28**, R. 109) ; *α-Hydroxyisovaleric Acid Nitrile*, $(CH_3)_2CH.CH(OH)CN$, decomposes at 135°, *α-Hydroxycaprylic Acid Nitrile, Œnanthol Hydrocyanide*, $CH_3[CH_2]_5CH(OH)CN$.

Halogen Substitution Products of the Aldehyde Cyanhydrins (A. **179**, 73) : *Chloral Cyanhydrin*, $CCl_3CH(OH)CN$, m.p. 61°, boils with decomposition at 215–230°. *Tribromolactic Acid Nitrile*, $CBr_3CH(OH)CN$. Both compounds can also be looked on as trihalides of orthotartronic acid nitriles. *Trichlorovalerolactic Acid Nitrile*, $CH_3CCl_2CHCl.CH(OH)CN$, m.p. 103°.

Ketone Cyanhydrins : *α-Hydroxyisobutyric Acid Nitrile, Acetone Cyanhydrin*, $(CH_3)_2C(OH)CN$, m.p.—19°, b.p.$_{23}$ 82°. *Methyl Ethyl Glycollic Acid Nitrile*, $(C_2H_5)(CH_3).C(OH)CN$, b.p.$_{20}$ 91°. *Diethyl Glycollic Acid Nitrile*, $(C_2H_5)_2.C(OH)CN$, b.p.$_{22}$ 110°. *β-Chloro-α-hydroxyisobutyric Acid Nitrile*, $ClCH_2C(CH_3)(OH)CN$, m.p.$_{22}$ 110°. *Methyl tert.-Butyl Glycollic Acid Nitrile*, $(CH_3)_3CC(CH_3).(OH)CN$, m.p. 94°, is prepared from pinacoline (A. **204**, 18 ; B. **14**, 1974 ; **39**, 1858 ; C. 1906, II. 596).

Nitriles of the hydroxy-acids have been prepared from the halogen glycolhydrins (p. 319) by the action of potassium cyanide. *Ethylene Cyanhydrin, β-Lactic Acid Nitrile*, $HOCH_2CH_2CN$, b.p. 220°, is also obtained from ethylene oxide and hydrocyanic acid. *β-Ethoxybutyronitrile*, $CH_3CH(OC_2H_5)CH_2CN$, b.p. 173°, is prepared from allyl cyanide and ethyl alcohol (B. **29**, 1425). *γ-Methoxybutyronitrile*, $CH_3O[CH_2]_3.CN$, b.p. 173° (B. **32**, 948).

ε-Phenoxycapronitrile, $C_6H_5O[CH_2]_5.CN$, m.p. 36°, from ε-chlorocapronitrile and sodium phenolate (B. **38**, 178).

The groups of substances, which are dealt with in the following sections, are closely connected with one another and with the hydroxy-carboxylic acids. When the alcoholic hydroxyl group of the latter is replaced by the groups $-NO_2$, $-NO$, $-NHOH$, and $-NH_2$, a whole series of *nitro-*, *nitroso-*, *hydroxylamine-* and *amino-carboxylic acids* are produced.

6. **Nitro-fatty Acids.** *α-Nitro-fatty Acids* are only known in the form of derivatives. When potassium nitrite acts on potassium chloracetate there is first formed potassium nitro-acetic acid which decomposes into nitromethane and potassium bicarbonate (comp. p. 149):

$$CH_2ClCOOK \xrightarrow{KNO_2} NO_2CH_2CO_2K \xrightarrow{H_2O} CH_3NO_2 + KHCO_3.$$

When silver nitrite and bromacetic ester react, the expected nitro-acetic ester is replaced by two peculiar bodies containing less water, which are derivatives of oxalic acid: *oxalic ester nitrile oxide*, $C_2H_5OCO.C\vdots N:O$, m.p. 111°, and *bis-anhydro-nitro-acetic ester*, $(C_2H_5OCOCNO)_2$, b.p.$_{11}$ 160°, which on reduction yields glycol, like a true nitro-acetic ester. Similarly, iodo-acetonitrile and silver nitrite do not yield nitro-acetonitrile, but a dimolecular body, deficient in water, *cyanomethazonic acid*, which perhaps should be considered as being *isonitroso-nitro-succinic acid nitrile*, $NC.C(NOH).C(NOOH)CN$ (comp. methazonic acid, p. 339) (B. **34**, 870).

The real *nitro-acetic ester*, $NO_2.CH_2.COOC_2H_5$, b.p.$_{10}$ 94°, is prepared from nitromalonic ester, $NO_2CH(COOC_2H_5)_2$ and KOH; also from α-nitrodimethyl acrylic ester, $(CH_3)_2C:C(NO_2)COOC_2H_5$, by the decomposing action of ammonia; also, particularly easily, from acetoacetic ester by the action of concentrated nitric acid and acetic anhydride, together with bis-anhydro-nitro-acetic ester (see above) (C. 1904, II. 640). Reduction changes it to hydroxylamino-acetic acid and glycocoll (C. 1901, II. 1259; comp. I. 881). Like other nitro-bodies, nitro-acetic acid forms salts (p. 149), $MeOON:CHCO_2C_2H_5$. When the ammonium salt is precipitated with mercuric chloride a very stable *mercury nitro-acetic ester*,  $O\!<\!\genfrac{}{}{0pt}{}{Hg}{ON}\!\!>\!C.CO_2C_2H_5$, is formed, which is soluble in alkalis and hydrochloric acid, and with bromine forms *nitrodibromacetic ester*, $NO_2CBr_2CO_2C_2H_5$, b.p.$_{11}$ 131–134° (B. **39**, 1956). Heating with ammonia at 100° converts it into *nitro-acetamide*, $NO_2CH_2CONH_2$, m.p. 101–102°, with decomposition. This can also be formed by alkaline decomposition of nitro-malonamide. Its silver salt reacting with iodo-alkyls give *O-ethers*, such as $CH_3OON:CHCONH_2$ and $C_2H_5OON:,CHCONH_2$, which decompose readily into aldehyde and *isonitroso-acetamide*, $HON:CHCONH_2$. *Nitrodibromacetamide*, $NO_2CBr_2CONH_2$, and *nitrobromacetamide*, $NO_2CHBrCONH_2$, m.p. 79° (C. 1906, I. 910; B. **37**, 4623). *Nitro-acetonitrile*, NO_2CH_2CN, b.p.$_{14}$ 96°, is prepared from methazonic acid (nitro-acetaldoxime, p. 339) and thionyl chloride. With bromine it gives *nitro-dibromacetonitrile*, NO_2CBr_2CN, b.p.$_{12}$ 58°, which is a different body from dibromoglyoxime peroxide (p. 250) (B. **41**, 1044).

Homologues of the α-nitro-fatty esters, such as *α-nitropropionic ester*, $CH_3CH(NO_2)CO_2C_2H_5$, b.p. 190–195°; *α-nitrobutyric ester*, $C_2H_5CH(NO_2)CO_2C_2H_5$, b.p.$_{20}$ 123°, are obtained from the alkyl-nitro-malonic esters and sodium alcoholate (C. 1904, II. 1600). *α-Nitro-isobutyric Acid*, $(CH_3)_2C:(NO_2)COOH$: *nitrile*, m.p. 53°, is obtained by oxidation of nitroso-isobutyric nitrile (p. 381) with nitric acid; *amide*, m.p. 118°.

β-Nitro-fatty Acids: *β-Nitropropionic Acid*, $NO_2CH_2CH_2CO_2H$, m.p. 66°, is prepared from β-iodopropionic and silver nitrite; *ethyl ester*, b.p. 161–165°. *β-Nitro-isovaleric Acid*, $(CH_3)_2C(NO_2).CH_2CO_2H$, is obtained together with *dinitropropane*, $(CH_3)_2C(NO_2)_2$, by the action of nitric acid on isovaleric acid (B. **15**, 2324).

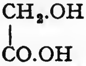
7. **Nitroso-fatty Acids.** From the examination of the nitroso-paraffins (p. 152) it is clear that the nitro-fatty acids, which contain the group —$CH_2.NO$ or $=CH.NO$, must undergo transformation into the isonitroso- or oximido-fatty acids, which will be considered later as derivatives of the aldehyde- and ketone-acids respectively (pp 410, 416, 424). On the other hand, oxidation by chlorine of hydroxyl-amino-isobutyric acid nitrile (see below) yields the *Nitrile* of *Nitroso-isobutyric Acid*, $(CH_3)_2C(NO)COOH$, m.p. 53°, to a blue liquid; *amide*, m.p. 158° with decomposition; *ester*, m.p. 89°; *amidine*, $(CH_3)_2C(NO)C(NH)NH_2$, is converted by hydrocyanic acid, etc., into a series of peculiar bases (B. **34**, 1863; **36**, 1283).

8. **Hydroxylamino-fatty Acids.** Their nitriles result from the combination of hydrocyanic acid with aldoximes and ketoximes (p. 382) (B. **29**, 65). *Hydroxyl-amino-acetic Acid*, $HONH.CH_2COOH$, m.p. 132°, is obtained from isonitramino-acetic acid (p. 397) and from nitro-acetic ester (see above), also from isobenzal-doxime acetic acid (Vol. II.) (B. **29**, 667). *α-Hydroxylaminobutyric Acid*, $CH_3.CH_2CH(NHOH)COOH$, decomposes at 166°; *nitrile*, m.p. 86°, results from propionaldoxime and HNC (B. **26**, 1548). *α-Hydroxylamino-isobutyric Acid*, $(CH_3)_2C(NHOH)COOH$, is prepared from isonitramino-isobutyric acid (p. 397); *nitrile*, m.p. 98°, is produced from acetoxime and HNC; further derivatives, see B. **34**, 1863.

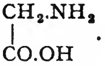
9. **Amidoxyl-fatty Acids** are isomeric with the hydroxylamino-fatty acids. *Amidoxyl-acetic Acid*, NH_2OCH_2COOH, is obtained by the breaking down of ethyl benzhydroxime acetic acid, $C_6H_5C(OC_2H_5):NOCH_2COOH$. *Homologues*, see B. **29**, 2654.

10. Amido- or Amino-fatty Acids.

In the amino-acids the alcoholic hydroxyl of the dihydric acids is replaced by the amido-group NH_2:


$\begin{array}{l} CH_2.OH \\ | \\ CO.OH \end{array}$

Glycollic Acid.

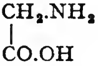

$\begin{array}{l} CH_2.NH_2 \\ | \\ CO.OH \end{array}$.

Glycolamino-acid.

It is simpler to consider them as being amino-derivatives of the monobasic fatty acids, produced by the replacement of one hydrogen atom in the latter by the amido-group:


$\begin{array}{l} CH_3 \\ | \\ CO.OH \end{array}$

Acetic Acid.


$\begin{array}{l} CH_2.NH_2 \\ | \\ CO.OH \end{array}$

Aminoacetic Acid.

Hence they are usually called *amino-* or *amido-fatty acids*.*

The firm union of the amino-group in them is a characteristic difference between these compounds and their isomeric acid amides. Boiling alkalis do not eliminate it (similar to the amines). Several of these amino-acids occur already formed in plant and animal organisms, to which great physiological importance is attached. They can be obtained from proteins by heating the latter with hydrochloric acid, or alkalis, or by the action of ferments or bacteria. They have received the name *alanines* or *glycocolls* from their most important representatives.

The general methods in use for preparing the amino-acids are:

(1) The transposition of the monohalogen fatty acids when heated with ammonia (similar to the formation of the amines from the alkylogens, p. 157):

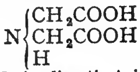
---

* Modern and stricter nomenclature reserves the term *amido-* for the —$CONH_2$ group.—(Tr.)

Thus chloracetic acid yields:

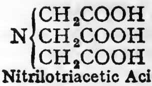
$$N\left\{\begin{matrix}CH_2COOH\\H\\H\end{matrix}\right.$$

Aminoacetic Acid.



$$N\left\{\begin{matrix}CH_2COOH\\CH_2COOH\\H\end{matrix}\right.$$

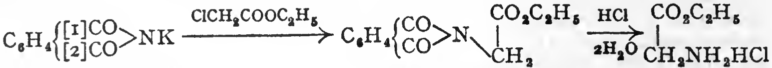
Iminodiacetic Acid.



$$N\left\{\begin{matrix}CH_2COOH\\CH_2COOH\\CH_2COOH\end{matrix}\right.$$

Nitrilotriacetic Acid.

(2) In the action of the halogen fatty acids on ammonia, phthalimide may be employed to promote the reaction, where the halogen fatty-acid esters are allowed to react with potassium phthalimide, after which the amino-acid is split off by hydrochloric acid at 200° C.:



$$C_6H_4\left\{\begin{matrix}[1]CO\\ [2]CO\end{matrix}\right\rangle NK \xrightarrow{ClCH_2COOC_2H_5} C_6H_4\left\{\begin{matrix}CO\\CO\end{matrix}\right\rangle N\diagdown\begin{matrix}CO_2C_2H_5\\|\\CH_2\end{matrix} \xrightarrow[2H_2O]{HCl} \begin{matrix}CO_2C_2H_5\\|\\CH_2NH_2HCl\end{matrix}$$

Potassium Phthalimide. Phthalyl Glycocoll Ester.

(3) The reduction of nitro- and isonitroso-acids (p. 380) with nascent hydrogen from zinc and hydrochloric acid or aluminium amalgam in ether (C. 1904, II. 1709):

$$\underset{\text{Nitroacetic Ester.}}{CH_2NO_2COOC_2H_5} \xrightarrow{6H} \underset{\text{Aminoacetic Acid.}}{CH_2NH_2COOH}$$

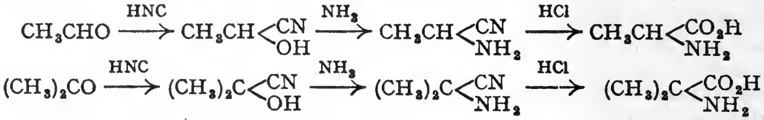
$$\underset{\text{Isobutyl Isonitroso-acetic Ester.}}{(CH_3)_2CHCH_2C(NOH)CO_2C_2H_5} \xrightarrow{4H} \underset{i\text{-Leucine}(\alpha\text{-Aminoisocaproic Acid}).}{(CH_3)_2CHCH_2CH(NH_2)COOH}$$

(4) Reaction of the cyano-fatty acids (*q.v.*) with nascent H (Zn and HCl, or by heating with HI), in the same manner that the amines are produced from the alkyl cyanides (p. 158):

$$\underset{\text{Cyanoformic Acid.}}{CN.COOH+2H_2}=\underset{\text{Aminoacetic Acid.}}{CH_2(NH_2)CO_2H}$$

This reaction connects the amino-fatty acids with the fatty acids containing an atom less of carbon, and also with the dicarboxylic acids of like carbon content, whose *half nitriles* are the cyano-fatty acids.

(5*a*) The nitriles of the α-amino-acids are prepared by allowing a calculated quantity of ammonia, in alcoholic solution, to act on the hydrocyanic acid addition-products of the aldehydes and ketones, and then setting free the hydrochlorides of the α-amino-acids from these by means of hydrochloric acid (B. **13**, 381; **14**, 1965):



$$CH_3CHO \xrightarrow{HNC} CH_3CH{<}\begin{matrix}CN\\OH\end{matrix} \xrightarrow{NH_3} CH_3CH{<}\begin{matrix}CN\\NH_2\end{matrix} \xrightarrow{HCl} CH_3CH{<}\begin{matrix}CO_2H\\NH_2\end{matrix}$$

$$(CH_3)_2CO \xrightarrow{HNC} (CH_3)_2C{<}\begin{matrix}CN\\OH\end{matrix} \xrightarrow{NH_3} (CH_3)_2C{<}\begin{matrix}CN\\NH_2\end{matrix} \xrightarrow{HCl} (CH_3)_2C{<}\begin{matrix}CO_2H\\NH_2\end{matrix}$$

(5*b*) Nitriles of α-amino-acids can also be synthetically obtained from the aldehyde-ammonias by means of hydrocyanic acid; also from aldehydes by means of ammonium cyanide (B. **14**, 2686):

$$CH_3CH{<}\begin{matrix}OH\\NH_2\end{matrix} \xrightarrow{HNC} CH_3CH{<}\begin{matrix}CN\\NH_2\end{matrix} \xleftarrow{NH_4NC} CH_3CHO.$$

Ketones also unite with ammonium cyanide to form nitriles of the α-amino-dialkyl acetic acids (B. **33**, 1900; **39**, 1181).

Aldehydes and ketones may, with advantage, be allowed to act on a mixture of potassium cyanide and ammonium chloride (B. **39**, 1722). When potassium cyanide reacts with aldehydes in bisulphite solution (p. 380) and is followed by primary and secondary amines, then alkyl and dialkyl aminonitriles are formed (B. **38**, 213).

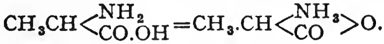
Hydrocyanic acid attaches itself similarly to the oximes (B. **25**, 2070), to the hydrazones, and to the *Schiff* bases, with the production of nitriles of α-hydroxylamino acids, phenylhydrazino-acids and alkylamino-acids (B. **25**, 2020; C. 1904, II. 945).

The methods (5*a*) and (5*b*) are only suitable for the production of α-amino-fatty acids, whilst the other methods serve also for the preparation of β-, γ-, and δ-amino-fatty acids, which are also produced:

(6) By the addition of ammonia to olefine monocarboxylic acids. (7*a*) By the oxidation of amino-ketones, *e.g.* diacetonamine (p. 230), and (7*b*) by the breaking down of the cyclic imines of glycols upon oxidation (see *piperidine*).

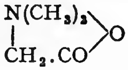
Properties.—The amino-acids are crystalline bodies usually possessing a sweet taste. They are readily soluble in water, but usually are insoluble in alcohol and ether.

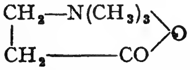
Constitution.—As the amino-acids contain both a carboxyl and an amino-group, they behave as both acids and bases. Since, however, the carboxyl and amino-groups mutually neutralize each other, the amino-acids show a neutral reaction, and it is very probable that both groups combine to produce a cyclic ammonium salt:

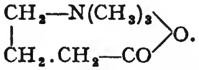


$$CH_3CH{<}{}^{NH_2}_{CO.OH} = CH_3.CH{<}{}^{NH_3}_{CO}{>}O.$$

This is supported by the existence and mode of formation of *trimethyl glycocoll* or *betaïne*, as well as of the homologous β- and γ-*betaïnes* (comp. pp. 386, 393):







The formation of salts provides a method of separation of the two groups (B. **35**, 589).

The *esters* of the α-amino-carboxylic acids are of special importance, partly as providing the materials from which the diazo-ester (below) is produced, and partly because it is by their preparation that the mixture of α-amino-acids which results from the hydrolysis of proteïns, can be separated and purified (B. **39**, 541).

These esters are best obtained as hydrochlorides by warming the acids with alcohols and hydrochloric acid. The free amino-esters are liquids which can be distilled under reduced pressure, possess the characteristics of amines, and are fairly easily hydrolyzed. Heat converts them into cyclic double amides (di-aci-piperazine) (p. 391).

Reactions.—The amino-acids form (1) metallic salts with metallic oxides and (2) ammonium salts with acids.

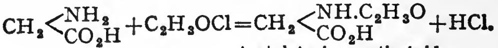
In the presence of alkalis and alkali earths, carbon dioxide forms salts of *carbamino-carboxylic acid*, of which the Ba or Ca salt, $\overline{OCO.NH.CH_2COOBa}$, is most suited for its separation on account of its low solubility (B. **39**, 397; Ch. Z. 1907, 937).

(3) The replacement of the carboxylic hydrogen by alcohol radicals produces *esters*, which are highly reactive.

(4) Phosphorous chloride converts the amino-acids, suspended in acetyl chloride, into hydrochlorides of the highly reactive *amino-acid chlorides* (*E. Fischer*, B. **38**, 2914):

$$NH_2CH_2COOH + PCl_5 = HCl.NH_2CH_2COCl + POCl_3.$$

(5) The hydrogen of the amino-group can also be replaced by acid and alcohol radicals. The *acid-derivatives* are obtained by the action of acid chlorides on an alkaline solution of the acid, or in presence of bicarbonate, or on the ester in a neutral solvent:



$$CH_2<\begin{matrix}NH_2\\CO_2H\end{matrix}+C_2H_3OCl=CH_2<\begin{matrix}NH.C_2H_3O\\CO_2H\end{matrix}+HCl.$$

Acetyl Amino-acetic Acid.

Acyl groups can be substituted into the amino-acids by means of acid anhydrides and acid azides (J. pr. Ch. [2] **70,** 57); the *formyl* group merely by warming with absolute formic acid (B. **38,** 3997). Those acyl derivatives which serve most suitably for identifying the amino-acids are the *benzoyl-*, *benzene sulphonic-*, and *naphthalene sulphonic-* compounds, such as $C_6H_5.CO.NHCH_2\text{-}COOH$, $C_6H_5SO_2.NHCH_2COOH$, $C_{10}H_7SO_2.NHCH_2COOH$. Another class of derivatives is the *phenyl ureïdo-acids,* such as $C_6H_5.NHCONHCH_2COOH$, produced by phenyl cyanate (Vol. II.) in alkaline solution (B. **35,** 3779; **39,** 2359). The amino-group in the acyl amino-acids is "neutralized" by the acyl groups; they are therefore stronger acids than the simple amino-acids, and many of them crystallize well. On the significance of acyl amino-acids to the structure of the di- and poly-peptides, see p. 391.

(6) *Separation of optical components from racemic mixtures* is brought about through the strychnine, brucine, morphine, or cinchonine salts of the benzoyl- and formyl-amino acids. The resolution of racemic alanine, *a*-amino-butyric acid, α-amino-isovaleric acid, leucine, aspartic acid, and glutaminic acid, has been carried out in this manner (B. **32,** 2451; **33,** 2370; **38,** 3997). The resolution of the racemic synthetic α-amino-acids is of importance because it completes the laboratory production of the natural α-amino-acids (from proteïns), which are all optically active. The resolution can also be carried out by the aid of yeasts, which consume either the *d*-form only, or only the *l*-form (C. 1906, II. 501).

(7) Amino-acids with alkyl groups attached to the nitrogen are obtained from the monohalogen fatty acids or from hydroxy-acid nitriles by the action of amines (J. pr. Ch. [2] **65,** 188):

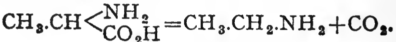
$$CH_2ClCOOH\xrightarrow{NH(CH_3)_2}CH_2<\begin{matrix}N(CH_3)_2\\COOH\end{matrix}\longrightarrow\begin{matrix}(CH_3)_2N\\NC\end{matrix}>CH_2\xrightarrow{NH(CH_3)_2}\begin{matrix}HO\\NC\end{matrix}>CH_2$$

(8) Continued methylation causes the amino-group to leave the molecule, whereby unsaturated acids result. Thus, α-aminopropionic acid yields acrylic acid; α-aminobutyric acid gives rise to crotonic acid (B. **21,** R. 86); α-amino-*n*-valeric acid yields propylidene acetic acid (B. **26,** R. 937).

(9) Hydriodic acid at 200° causes the exchange of the amino-group for hydrogen, whereby the acid is converted into a fatty acid (B. **24,** R. 900).

(10) Boiling with alkalis does not affect the amino-acids, but fusion with potassium hydroxide causes decomposition into ammonia or amines and salts of fatty acids.

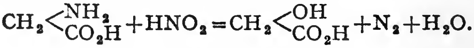
(11) Dry distillation, especially in presence of barium oxide, decomposes the acids into amines and CO_2:



$$CH_3.CH<\begin{matrix}NH_2\\CO_2H\end{matrix}=CH_3.CH_2.NH_2+CO_2.$$

Ethylamine.

(12) Nitrous acid converts the amino-acids into hydroxy-acids:



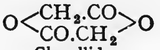
$$CH_2<\begin{matrix}NH_2\\CO_2H\end{matrix}+HNO_2=CH_2<\begin{matrix}OH\\CO_2H\end{matrix}+N_2+H_2O.$$

(13) The amino-ester hydrochlorides are changed by potassium nitrite into diazo-fatty esters (p. 403), the formation of which serves for the detection of small quantities of amino-acids (B. **17,** 959). In the presence of excess of hydrochloric acids, chloro-fatty acids are formed (C. 1901, I. 98). Similarly, nitrosyl bromide produces α-bromo-fatty acids.

Ferric chloride produces a red coloration with all the amino-acids, which is destroyed by acids.

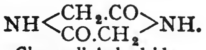
Reduction of amino-esters produces amino-aldehydes (B. **41,** 956); *oxidation* with H_2O_2, see C. 1908, I. 1164.

One of the chief characteristics of the α-amino-fatty acids is that when they lose water they yield cyclic double acid amides corresponding with the cyclic double esters of the alpha-hydroxy-acids or lactides.



$O<\begin{matrix}CH_2.CO\\CO.CH_2\end{matrix}>O$

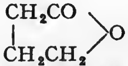
Glycollide.



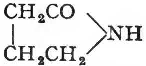
$NH<\begin{matrix}CH_2.CO\\CO.CH_2\end{matrix}>NH.$

Glycocoll Anhydride.

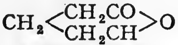
The γ- and δ-amino-acids, and amino-acids possessing long chains, however, are capable of forming cyclic, simple acid amides, the *lactams*, corresponding with the lactones, the cyclic, simple esters of the hydroxy-acids :



Butyrolactone.

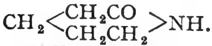


γ-Butyrolactam, Pyrrolidone.



$CH_2<\begin{matrix}CH_2CO\\CH_2CH_2\end{matrix}>O$

δ-Valerolactone.

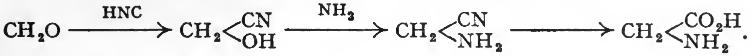


$CH_2<\begin{matrix}CH_2CO\\CH_2CH_2\end{matrix}>NH.$

δ-Valerolactam, α-Oxopiperidine.

α-Amino-fatty Acids.

Glycocoll, *Glycin, Amino-acetic Acid* [Amino-ethane Acid], $\begin{matrix}COOH\\|\\CH_2NH_2\end{matrix}$ or $\begin{matrix}COO\\|\quad|\\CH_2NH_3\end{matrix}$, m.p. 232–236°, is obtained by the general methods of preparation (pp. 381, 382): (1) From monochloracetic acid and ammonia (di- and triglycolamidic acids being formed at the same time); or by warming monochloracetic acid with dry ammonium carbonate (B. **16,** 2827 ; **33,** 70) ; (2) from phthalyl glycocoll ester (B. **22,** 426) ; (3) by the reduction of nitro-acetic acid ; (4) of cyanoformic acid ; (5) by heating methylene amino-acetonitrile with hydrochloric acid, when it changes to the hydrochloride of glycine ester (B. **29,** 762) ; (6) from methylene cyanhydrin, the product obtained by the union of formaldehyde and hydrocyanic acid. Ammonia converts it into glycocoll nitrile, which is converted into glycocoll by boiling barium hydroxide solution (A. **278,** 229 ; J. pr. Ch. [2] **65,** 188) :



$$CH_2O\xrightarrow{HNC}CH_2<\begin{matrix}CN\\OH\end{matrix}\xrightarrow{NH_3}CH_2<\begin{matrix}CN\\NH_2\end{matrix}\longrightarrow CH_2<\begin{matrix}CO_2H\\NH_2\end{matrix}.$$

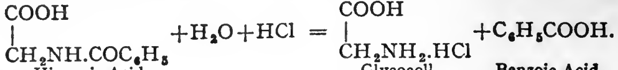
Glycocoll may be prepared by methods 1, 2, 5, and 6, or by the decomposition of hippuric acid (see below). A rather striking formation of glycocoll is observed (7) by conducting cyanogen gas into boiling hydriodic acid :

$$CN.CN+2H_2O+2H_2=HOOC.CH_2NH_2+NH_3;$$

and, further, (8) by allowing ammonium cyanide and sulphuric acid to act on glyoxal, when the latter probably at first yields formaldehyde (B. **15,** 3087) ; (9) from glyoxylic acid (p. 388) by the action of ammonia, with the intermediate formation of *formyl glycocoll* (B. **35,** 2438).

History and Occurrence.—*Braconnot* (1820) first obtained glycocoll by decomposing glue with boiling sulphuric acid. It owes its name to this method of formation and to its sweet taste : γλυκύς, sweet, κόλλα, glue.

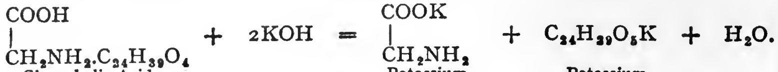
Dessaignes (1846) showed that glycocoll was formed as a decomposition product when hippuric acid was boiled with concentrated hydrochloric acid:



$$\begin{array}{l}COOH\\ |\\ CH_2NH.COC_6H_5\end{array} + H_2O + HCl = \begin{array}{l}COOH\\ |\\ CH_2NH_2.HCl\end{array} + C_6H_5COOH.$$

Hippuric Acid Benzoyl Glycocoll. Glycocoll Hydrochloride. Benzoic Acid.

Strecker (1848) observed that glycocoll appeared from an analogous decomposition of the glycocholic acid occurring in bile (comp. taurine, p. 326);



$$\begin{array}{l}COOH\\ |\\ CH_2NH_2.C_{24}H_{39}O_4\end{array} + 2KOH = \begin{array}{l}COOK\\ |\\ CH_2NH_2\end{array} + C_{24}H_{39}O_5K + H_2O.$$

Glycocholic Acid. Potassium Amino-acetate. Potassium Cholate.

Since then, glycocoll has been found to constitute the break-down product of many other animal and vegetable proteins; it is especially abundant in the fibroïn of silk.

Glycocoll was first (1858) prepared artificially by ***Perkin*** and ***Duppa***, when they allowed ammonia to act on bromacetic acid.

Properties.—Glycocoll crystallizes from water in large, rhombic prisms, which are soluble in 4 parts of cold water. It is insoluble in alcohol and ether. It possesses a sweetish taste, and melts with decomposition. Heated with barium hydroxide it breaks up into methylamine and carbon dioxide; nitrous acid converts it into glycollic acid. Ferric chloride imparts an intense red coloration to glycocoll solutions; acids discharge this, but ammonia restores it.

Metallic Salts.—An aqueous solution of glycocoll will dissolve many metallic oxides, forming salts. Of these, the *copper salt*, $(C_2H_4NO_2)_2Cu + H_2O$, is very characteristic, and crystallizes in dark blue needles: *silver salt*, $C_2H_4NO_2Ag$, crystallizes on standing over sulphuric acid. The combinations of glycocoll with salts, *e.g.* $C_2H_5NO_2.KNO_3$, $C_2H_5NO_2.AgNO_3$, are mostly crystalline.

Ammonium Salts.—Glycocoll yields the following compounds with hydrochloric acid: $C_2H_5NO_2.HCl$ and $2(C_2H_5NO_2).HCl$. The first is obtained with an excess of hydrochloric acid, and crystallizes in long prisms: *nitrate*, $C_2H_5NO_2$-HNO_3, forms large prisms.

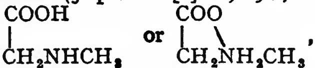
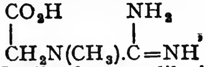
Amino-acetic Ethyl Ester, *Glycocollic Ester*, $NH_2.CH_2COOC_2H_5$, b.p. 149°, b.p.$_{10}$ 52°, is an oil resembling cocoa in odour, which is easily soluble in ether, alcohol, and water. In aqueous solution, however, it changes into di-aci-piperazine (p. 391), and in ether into tri-glycyl-glycine ester (p. 392). The ester is particularly suitable for the preparation of various derivatives of glycocoll (B. **34**, 436). *Glycocollic Ester Hydrochloride*, $HCl.NH_2.CH_2COOC_2H_5$, m.p. 144°, is formed by the passage of HCl gas into a mixture of alcohol and glycocoll, and can be employed as a method of estimation of glycocoll on account of its slight solubility in alcoholic hydrochloric acid (B. **39**, 548). It is also obtained from methylene-amino-acetonitrile (see below), aceturic acid (p. 388) (B. **29**, 760), or from the reaction product of hexamethylamine and potassium chloroacetate (C. 1899, I. 183, 420), by the action of alcoholic hydrochloric acid, whereby the ester hydrochloride results. This is also formed by pouring excess of alcohol on *Glycyl Chloride Hydrochloride*, $HCl.NH_2CH_2COCl$, which is prepared from *precipitated* glycocoll and phosphorus pentachloride in acetyl chloride, as a crystalline powder (B. **38**, 2914).

Glycocollamide, Amino-acetamide, $NH_2CH_2CONH_2$, is produced when glycocoll is heated with alcoholic ammonia to 160°. It is a white mass which dissolves readily in water, and reacts strongly alkaline. The HCl-salt results on heating chloracetic ester to 70° with alcoholic ammonia.

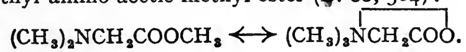
Glycocoll Hydrazide, $NH_2CH_2CO.NHNH_2$, m.p. 80–85°, is obtained from glycocoll ester and hydrazine hydrate, as a hygroscopic crystalline mass; *hydrochloride*, $C_2H_7N_3O.2HCl$, m.p. 201° (J. pr. Ch. [2] **70**, 102).

Glycocoll Nitrile, Amino-acetonitrile, NH_2CH_2CN, b.p.$_{15}$ 58°, is prepared from glycoll nitrile and alcoholic ammonia at 0°; *hydrochloride*, m.p. 165°; *sulphate*, $C_2H_4N_2.H_2SO_4$, m.p. 101° (J. pr. Ch. [2] **65**, 189; B. **36**, 1511).

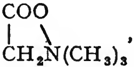
Methylene Amino-acetonitrile, $CH_2{=}NCH_2CN$, m.p. 129°, with decomposition, is formed from formaldehyde, ammonium chloride, and potassium cyanide; also from glycocoll nitrile and formaldehyde. It may consist of a double molecule. It is remarkable for its crystallization (J. pr. Ch. [2] **65**, 192; B. **36**, 1506).

Methyl Glycocoll, *Sarcosine*,  $\begin{array}{l}COOH\\ |\\ CH_2NHCH_3\end{array}$ or $\begin{array}{l}COO\\ |\quad\backslash\\ CH_2NH_2CH_3\end{array}$, m.p. 210–220° with decomposition, was first obtained by *Liebig* (1847) as a decomposition product of the creatine contained in beef extract. Its name is derived from σάρξ, flesh. *Volhard* (1862) prepared it synthetically by the action of methylamine on monochloracetic acid; and it is also produced when creatine or *methyl glycocyamine*,  $\begin{array}{ll}CO_2H & NH_2\\ | & |\\ CH_2N(CH_3).C{=}NH\end{array}$, or *caffeïne* is heated with barium hydroxide solution. It dissolves readily in water but with difficulty in alcohol. The *nitrile* of sarcosine is obtained together with methylamine from methylene cyanhydrin, the additive product of formaldehyde and hydrocyanic acid (A. **279**, 39; J. pr. Ch. [2] **65**, 188). When melted it decomposes into carbon dioxide and dimethylamine, yielding at the same time sarcosine anhydride (p. 392). It forms salts with acids, which show an acid reaction. Ignited with soda-lime it evolves methylamine. Sarcosine yields *methyl hydantoïn* with cyanogen chloride and *creatine* (*q.v.*) with cyanamide. *Sarcosine Ethyl Ester*, CH_3NHCH_2-$CO_2C_2H_5$, b.p.$_{10}$ 43° (B. **34**, 452).

Dimethyl Glycocoll, $(CH_3)_2NCH_2COOH$, is prepared by the hydrolysis of its *nitrile, dimethylamino-acetonitrile*, $(CH_3)_2NCH_2CN$, b.p. 138°. This is formed by the action of dimethylamine on methylene-amino-acetonitrile (above) or on glycollic nitrile. *Dimethylamino-acetic Methyl Ester*, $(CH_3)_2NCH_2COOCH_3$, b.p. 135°, is obtained from the interaction of chloracetic acid and dimethylamine. It is isomeric with betaïne, into which it changes when heated. Betaïne, on the other hand, when heated above its melting point (293°) is isomerized to a large extent into dimethyl amino-acetic methyl ester (B. **35**, 584):



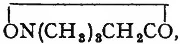
$$(CH_3)_2NCH_2COOCH_3 \longleftrightarrow (CH_3)_3\overline{NCH_2COO}.$$

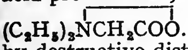
Trimethyl Glycocoll, *Betaïne, Oxyneurine, Lycine*,  $\begin{array}{l}COO\\ |\quad\backslash\\ CH_2N(CH_3)_3\end{array}$, has already been mentioned (p. 330) in connection with *choline*, from which it is prepared by oxidation.

Its *hydrochloride* is prepared by the union of monochloracetic acid with trimethylamine (B. **2**, 167; **3**, 161; **35**, 603):

$$ClCH_2COOH+N(CH_3)_3=ClN(CH_3)_3CH_2COOH.$$

Similarly, chloroacetic ester and trimethylamine yield *Betaïne Ester Hydrochloride*, $ClN(CH_3)_3CH_2.CO_2C_2H_5$, m.p. 143° (B. **38**, 167). *Betaïne* is also obtained by the methylation of glycocoll by means of methyl iodide, potassium hydroxide, and methyl alcohol. It occurs in beet-root (*Beta vulgaris*) (*Scheibler*, B. **2**, 292; **3**, 155), and is to be extracted from the "melasse" of the beet-sugar factory, in which it is the substance which gives rise to the trimethylamine obtained therefrom (p. 165). It also occurs in the leaves and stalks of *Lycium barbarum*, in cotton seeds, and in germ of malt and wheat (B. **26**, 2151).

It crystallizes in deliquescent crystals in which the *acid*, $HON(CH_3)_3CH_2COOH$, may be present. At 100° this ammonium hydroxide derivative loses one molecule of water, forming a cyclic *ammonium salt*,  $\overline{ON(CH_3)_3CH_2CO}$, m.p. 293°, with conversion into dimethyl amino-acetic methyl ester (see above). Iodine in potassium iodide precipitates a *periodide* from an aqueous solution of betaïne (C. 1904, II. 950).

The action of ethylamine, diethylamine and triethylamine on chloracetic acid produces *ethyl glycocoll, diethyl glycocoll*, and *triethyl glycocoll, triethyl betaïne*,  $(C_2H_5)_3\overline{NCH_2COO}$. Similarly to betaïne itself, the latter compound is converted by destructive distillation into *diethylamine acetic ethyl ester*, b.p. 177°, the iodoethyloxide of which is reconverted by silver oxide into triethyl betaïne. Similar changes have been observed with *dimethyl ethyl betaïnes* and *methyl diethyl betaïne*

(B. **35**, 584). The *homologous betaines* can also be prepared by the addition of iodo-alkyls to dialkylamine acetonitriles and the subsequent saponification of the iodo-alkylate formed. The *dialkylamino-acetonitriles* just referred to can be synthesized from formaldehyde, hydrocyanic acid, and dialkylamines (B. **36**, 4188).

$$(C_2H_5)_2NCH_2CN \xrightarrow{CH_3I} (C_2H_5)_2N(CH_3I)CH_2CN \longrightarrow (C_2H_5)_2\overline{N(CH_3)CH_2COO}.$$

Formyl Glycocoll, *Formamine Acetic Acid,* $HCONH.CH_2COOH$, m.p. 151–152°, is prepared by heating glycocoll with formic acid to 100°; and from glyoxylic acid and ammonia (B. **36**, 2525; **38**, 3999).

$$\underset{\text{Glyoxylic Acid.}}{2CHO.COOH} + NH_3 = \underset{\text{Formyl Glycine.}}{HCO.NH.CH_2COOH} + CO_2 + H_2O.$$

Acetyl Glycocoll, *Acetamine Acetic Acid, Aceturic Acid,* $CH_3CONH.CH_2COOH$, m.p. 206°, results from the action of acetyl chloride on silver glycocoll; from acetamide and monochloracetic acid; from ammonia and a mixture of glyoxylic and pyroracemic acids (B. **36**, 2526). It is readily soluble in water and alcohol, and behaves like a monobasic acid (B. **17**, 1664).

More important are *hippuric acid* or *benzoyl glycocoll* (*q.v.*) and glycocholic acid (*q.v.*) which have already been referred to in connection with glycocoll, and which will be dealt with later. They are similarly constituted to aceturic acid. *Naphthalene Sulphoglycine,* $C_{10}H_7SO_2NH.CH_2COOH$, m.p. 156° (B. **35**, 3779).

Iminodiacetic acid and nitrilotriacetic acid bear the same relation to glycocoll that di- and trihydroxy-ethylamine sustain to hydroxy-ethylamine:

$$\begin{array}{lll} NH_2CH_2CO_2H & NH(CH_2.CO_2H)_2 & N(CH_2.CO_2H)_3 \\ NH_2CH_2CH_2OH & NH(CH_2CH_2OH)_2 & N(CH_2CH_2OH)_3. \end{array}$$

These compounds are formed on boiling monochloracetic acid with concentrated aqueous ammonia (A. **122**, 269; **145**, 49; **149**, 88).

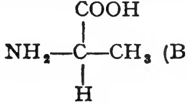
Iminodiacetic Acid, $NH(CH_2CO_2H)_2$, m.p. 225°, forms salts both with acids and bases, whilst *Nitrilotriacetic Acid,* $N(CH_2CO_2H)_3$, cannot unite with acids.

Imino-acetonitrile, $NH(CH_2CN)_2$, m.p. 75°, and *Nitrilo-acetonitrile,* $N(CH_2CN)_3$, m.p. 126°, are obtained from methylene cyanhydrin and ammonia (A. **278**, 229; **279**, 39). *Dimethyl Dicyano-methyl Ammonium Bromide,* $(CH_3)_2NBr(CH_2CN)_2$, is prepared from dimethylamino-acetonitrile and bromacetonitrile (B. **41**, 2123).

Alanine, *α-Aminopropionic Acid,* $CH_3\overset{*}{C}H(NH_2)CO_2H$, or $CH_3\overset{*}{C}H\overline{(NH_3)COO}$, m.p 293° with decomposition on being rapidly heated, is derived from α-chloro- and α-bromo-propionic acid by means of ammonia; also from aldehyde-ammonia, hydrocyanic acid, and hydrochloric acid; or aldehyde, ammonium cyanide, and hydrochloric acid (B. **41**, 2061), by hydrolysis of the intermediate *α-amino-propionitrile,* $CH_3CH(NH_2)CN$. This can be precipitated as *sulphate* from an alcoholic solution of aldehyde-ammonia and hydrocyanic acid by sulphuric acid, and may be resolved into its optically active components by formation of the *tartrates* (p. 384) (C. 1904, I. 360).

Synthetic *alanine*, of which the name refers to its connection with aldehyde-ammonia, is the racemic or [*d*+*l*] form of α-amino-propionic acid. It crystallizes from water in aggregates of hard needles; it is soluble in 3 parts of water, less easily in alcohol, and not at all in ether. On being quickly heated, it melts with partial decomposition, partially into ethylamine and CO_2, and partially into aldehyde, CO, and ammonia (B. **25**, 3502; **32**, 245). *Alanine Ethyl Ester,* $CH_3CH(NH_2)COOC_2H_5$, b.p.$_{11}$ 48°; *hydrochloride* is easily soluble in alcohol, contrary to glycine ester hydrochloride (B. **34**, 442). *Alanine Chloride Hydrochloride,* $CH_3CH(NH_3Cl)COCl$, is a white crystalline powder (B. **38**, 2917). *β-Naphthalene Sulpho-alanine,* $C_{10}H_7SO_2.NHCH(CH_3)COOH$, m.p. 152°. *Benzoyl Alanine,* $C_6H_5CO.NHCH(CH_3)COOH$, m.p. 165°, is resolved by means of brucine into the components [*d*- and *l*]- benzoyl alanine, which, on hydrolysis, yield *l*- and *d*-alanine.

d-Alanin also occurs as a product of hydrolytic decomposition of many proteins; from fibroïn of silk it is obtained by means of its *ester.* It forms rhombic crystals, which decompose at 297°. In aqueous solution its rotatory power is small, $[\alpha]_D^{20}=+2{\cdot}7°$; in hydrochloric acid solution it is much greater, $[\alpha]_D^{20}=+10{\cdot}4°$ (B. **39**, 462; **40**, 3721).

Nitrous acid converts *d*-alanine into the ordinary *d*-lactic acid (p. 364); on the other hand, nitrosyl bromide (p. 384) changes *d*-alanine into *l*-bromopropionic acid, which with ammonia yields *l*-alanine. This, with nitrosyl bromide, gives *d*-bromopropionic acid, which ammonia converts into *d*-alanine (*Walden's* inversion, p. 364; B. **40**, 3704). *d*-Alanine is also obtained by the reduction, with sodium amalgam, of *l*-β-chloralanine, $ClH_2CH(NH_2)COOH$. The ester of this acid is obtained from *l*-serine ester (β-hydroxy-α-aminopropionic ester) and PCl_5; since *l*-serine can be converted into *d*-glyceric acid and this into *l*-tartaric acid, the formula of *d*-alanine must be  $NH_2\text{—}\overset{\displaystyle COOH}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}\text{—}CH_3$ (B. **40**, 3717) (see also the considerations on the configuration of the carbohydrates).

Iodomethane and sodium hydroxide solution convert *d*-alanine into *l-Trimethyl Propionic Betaïne*, $(CH_3)_3NCH(CH_3)COO$, which also results from the interaction of *d*-α-bromopropionic acid and trimethylamine (B. **40**, 5000). *Triethyl Propionic Betaïne* is formed by hydrolysis of the *iodo-ethylate* of *Diethylaminopropionitrile*, $(C_2H_5)_2NCH(CH_3)CN$, b.p.$_{27}$ 81°, the reaction product of lactic acid nitrile and diethylamine (B. **36**, 4188).

Iminodipropionic Acid, $\begin{matrix}CH_3\\HOCO\end{matrix}\!>\!CH\text{—}NH\text{—}CH\!<\!\begin{matrix}CH_3\\COOH\end{matrix}$, contains *two asymmetric* carbon atoms, giving rise to two optically inactive forms, m.p. 255°, corresponding with mesotartaric acid, and m.p. 235°, corresponding with racemic acid. The *monamides*, m.ps. 332° and 210°, are formed by the prolonged interaction of dilute hydrocyanic acid and aldehyde-ammonia at ordinary temperatures, together with *iminodipropionimide*, $NH[CH(CH_3)CO]_2NH$, m.p. 186°, alanine, and other substances (B. **39**, 3942).

Higher homologues of α-amino-acids are prepared mainly by the general methods (1) from α-halogen-fatty acids and (5) from the nitriles of α-hydroxy-acids and ammonia.

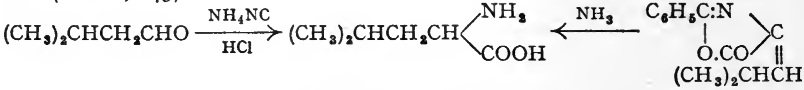
α-Amino-n-butyric Acid, $CH_3CH_2\overset{*}{C}H(NH_2)COOH$, m.p. 307° with decomposition, is resolved by means of the morphine salt of the *benzoyl*-derivative, *d*-acid $[\alpha]_D^{20}=+8°$, *l*-acid $[\alpha]_D^{20}=-7{\cdot}9°$; *ethyl ester*, b.p.$_{11}$ 61° (B. **33**, 2387; **34**, 443); *nitrile* (B. **41**, 2062). *α-Amino-isobutyric Acid*, $(CH_3)_2C(NH_2)CO_2H$, sublimes at 280° without melting, and is formed also by oxidation of diacetonamine sulphate; *nitrile*, b.p.$_{12}$ 50°, is prepared from acetone and ammonium cyanide (B. **33**, 1900; **39**, 1181, 1726). *α-Amino-valeric Acid*, $CH_3[CH_2]_2CH(NH_2)COOH$, is formed also by oxidation of benzoyl coniine (B. **19**, 500); *ethyl ester*, b.p.$_8$ 68° (B. **35**, 1004).

α-Amino-isovaleric Acid, Valine, Butalanine, $(CH_3)_2CH\overset{*}{C}H(NH_2)COOH$, decomposes 298°. The inactive acid results from α-bromisovaleric acid and ammonia; *ethyl ester*, b.p.$_8$ 63°. *Formyl Valine*, $HCONHCH(C_3H_7)COOH$, m.p. 140–145°, is produced by heating valine and formic acid together. It is resolved by means of its brucine salts, the *l*- and *d*-formyl valine, yielding *l-Valine* and *d-Valine*. The latter, m.p. 315°, $[\alpha]_D^{20}=+6{\cdot}42°$, in aqueous solution and $+28{\cdot}8°$ in hydrochloric acid, is a decomposition product of protein bodies —in the germs of the lupin, horn, caseïn, from protamines, and from the pancreas of oxen. *l*-Valine has a much sweeter taste than *d*-valine (B. **39**, 2320). *α-Amino Methyl Ethyl Acetic Acid*, $(C_2H_5)(CH_3)C(NH_2)COOH$, is prepared from methyl ethyl ketone, etc.; *ethyl ester*, b.p.$_{20}$ 66° (B. **35**, 400; **39**, 1189).

α-Aminocaproic Acids. *α-Amino-n-caproic Acid*, $CH_3[CH_2]_3\overset{*}{C}H(NH_2)COOH$, is prepared from α-bromo-n-caproic acid and ammonia. It is resolved into its optical component by means of its *benzoyl*-derivative (B. **33**, 2381; **34**, 3764).

α-Amino-isocaproic Acids. Leucine.—$(CH_3)_2CHCH_2\overset{*}{C}H(NH_2)COOH$, optically active leucine. Leucine (from λευκός, glistening white, referring to the appearance of the scaly crystals) occurs in different animal fluids, in the pancreas, in the spleen, in the lymph-glands, and is physiologically very important. It is formed by the decay of proteins, or when they are boiled with alkalis and acids. It is prepared by heating horn, the dried cervical ligament of oxen, or from casein with dilute sulphuric acid. Its purification is best effected by conversion into the ester (B. **34,** 446; C. 1908, I. 1633). Leucine is also obtained from vegetable proteins such as that of the lupin. *Strecker* (1848) showed that when it was treated with nitrous acid it passed into a hydroxycaproic acid, *leucic acid*, m.p. 73°, p. 366.

The naturally occurring leucine, m.p. 270°, sublimes unaltered when carefully heated, but decomposes on rapid rise of temperature into amylamine and CO_2. It forms shining leaflets, which feel greasy to the touch. It is soluble in 48 parts of water and 800 parts of hot alcohol. It is optically active, the *free acid* rotating the plane of polarization to the *left*, whilst its *hydrochloride* rotates it to the *right*. When heated with alkalis it becomes inactive and is then identical with that synthesized from *isovaleraldehyde*, ammonium cyanide, and hydrochloric acid; or by decomposing the condensation product of isobutyraldehyde and hippuric acid (A. **316,** 145):



$$(CH_3)_2CHCH_2CHO \xrightarrow[HCl]{NH_4NC} (CH_3)_2CHCH_2CH\begin{matrix}NH_2\\COOH\end{matrix} \xleftarrow{NH_3} \begin{matrix}C_6H_5C{:}N\\ |\\ O.CO\end{matrix}\!\!>\!C \atop \qquad\qquad \| \atop \qquad\qquad (CH_3)_2CHCH$$

The resolution of the rac.-*benzoyl leucine*, $(CH_3)_2CHCH_2CH(NHCOC_6H_5)COOH$, by means of cinchonine produces *benzoyl d-leucine* (lævo-rotatory) and *benzoyl l-leucine* (dextro-rotatory), from which hydrolysis liberates *d-leucine* (dextro-rotatory), and *l-leucine* (lævo-rotatory) identical with the naturally occurring substance. It is more convenient to resolve by means of *[d+l]-formyl leucine*, $HCO.NHCH(C_4H_9).COOH$ (B. **38,** 3997). *d*-Leucine is also obtainable from *l*-leucine by *Penicillium glaucum;* its hydrochloride is lævo-rotatory (B. **24,** 669; **26,** 56; **33,** 2370). *Leucine Ethyl Ester*, b.p. 196°. *Acetyl Leucine*, m.p. 160° (B. **34,** 433). *Leucine Chloride Hydrochloride*, $C_4H_9CH(NH_3Cl)COCl$ (B. **38,** 615).

a-Amino-sec.-*butyl Acetic Acid, Isoleucine*, $\genfrac{}{}{0pt}{}{C_2H_5}{CH_3}\!>\!\overset{*}{C}H.\overset{*}{C}H(NH_2)COOH$, contains 2 asymmetric carbon atoms, and therefore gives rise to 4 optically active components and 2 racemic forms. A *d-isoleucine*, m.p. 280°, with decomposition, $[a]_D^{20} = +9{\cdot}7$ in water, $+36{\cdot}8$ in hydrochloric acid, occurs together with leucine in beet-root melasse, and as a decomposition product of proteins. Synthetically, rac.-isoleucine is produced by reduction of *a*-hydroximino-isobutyl acetic acid (p. 410), and from *a*-bromo-sec.-butyl acetic acid and ammonia. *d*-Isoleucine is prepared from *d*-valeric aldehyde by the cyanhydrin synthesis (B. **40,** 2538; **41,** 1453).

a-Amino-œnanthic Acid, $CH_3[CH_2]_4CH(NH_2)CO_2H$ (B. **8,** 1168). *a-Amino caprylic Acid*, $CH_3[CH_2]_5CH(NH_2)CO_2H$ (A. **176,** 344). *a-Aminopalmitic Acid*, $CH_3[CH_2]_{13}CH(NH_2)CO_2H$ (B. **24,** 941). *a-Aminostearic Acid*, $CH_3[CH_2]_{15}CH(NH_2).CO_2H$, m.p. 221° (B. **24,** 2395).

DIPEPTIDES AND POLYPEPTIDES

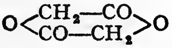
As has repeatedly been mentioned, the simple *a*-amino-acids, such as glycocoll, alanine, valine, and leucine, occur together, and also with such complicated substances as serine, proline, cystine, asparagine, lysine, arginine, histidine, and tyrosine, as products of the hydrolytic decomposition of proteins. It is probable that these breakdown bodies are *united with one another in the protein molecule through their amide groups*.

This question has been attacked both synthetically and analytically (*E. Fischer:* Untersuchung über Amino-säuren, Polypeptide und Proteïne, Berlin, 1906; *Th. Curtius:* Verkettung von Amino-säuren) (J. pr. Ch. [2] **70,** 57). In synthesis, the esters, chlorides, and azides of the aminocarboxylic acids themselves or of the substances which go to produce them, have been employed; and by their means the *aminacyl* residue has been substituted into the amino-group of other amino-acids, and the process has been successively repeated. The aminacyl aminocarboxylic acids produced have been named by *E. Fischer*, *peptides* because of their comparability with the natural *peptones* (protein products of digestion). They are classified according to the number of the connected amino-acids—*di-*, *tri-*, *tetra-peptides*, etc.

1. **Dipeptides and their inner anhydrides**, *cyclic double amides*, *αγ-Dioxopiperazines.* α-Amino-esters, when heated or even on standing in aqueous solution, part with alcohol and form dimolecular cyclic amides, corresponding with the lactides (p. 385):

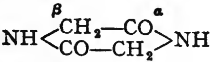
$$2NH_2CH_2COOC_2H_5 = NH\left\langle\begin{matrix}CH_2—CO\\CO—CH_2\end{matrix}\right\rangle NH + 2C_2H_5OH.$$

The fundamental substance, to which such compounds can be referred as being oxygen substitution products, is *diethylene diamine* or *piperazine* (p. 336), whence the names *αγ-diketo-*, *diaci-*, or *dioxopiperazine :*



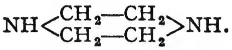
$$O\left\langle\begin{matrix}CH_2—CO\\CO—CH_2\end{matrix}\right\rangle O$$

Diglycollide.



$$NH\left\langle\begin{matrix}\overset{\beta}{C}H_2—\overset{\alpha}{CO}\\\underset{\gamma}{C}O—\underset{\delta}{C}H_2\end{matrix}\right\rangle NH$$

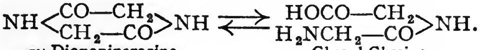
αγ-Dioxopiperazine.



$$NH\left\langle\begin{matrix}CH_2—CH_2\\CH_2—CH_2\end{matrix}\right\rangle NH.$$

Piperazine.

When warmed for a short time with hydrochloric or hydrobromic acid, or when shaken with dilute alkalis, the dioxopiperazine is split up into the dipeptide, which when melted, or when its ester is heated, easily changes into the dioxopiperazine:



$$NH\left\langle\begin{matrix}CO—CH_2\\CH_2—CO\end{matrix}\right\rangle NH \rightleftarrows \begin{matrix}HOCO—CH_2\\H_2NCH_2—CO\end{matrix}\Big\rangle NH.$$

αγ-Dioxopiperazine. Glycyl Glycine (the simplest dipeptide).

Unsymmetrically substituted dioxopiperazines, such as leucyl glycine anhydride, can be split into two different dipeptides, from which the same anhydride can be reformed.

2. **Dipeptides** and **polypeptides** are obtained in the following manner:—(*a*) Chlorides of the α-halogen fatty acids react with α-amino-acids to form α-halogen acylamino-acids, which with ammonia give dipeptides. These by further treatment with α-halogen acyl chlorides and ammonia yield tripeptides, and these tetrapeptides, pentapeptides, and so on:

$$\underset{\text{Chloracetyl Glycine.}}{ClCH_2CO.NHCH_2COOH} \xrightarrow{NH_3} \underset{\text{Glycyl Glycine.}}{NH_2CH_2CO.NHCH_2COOH} \longrightarrow$$

$$\underset{\text{Chloracetyl Glycyl Glycine.}}{ClCH_2CO.NHCH_2CO.NHCH_2COOH} \xrightarrow{NH_3}$$

$$\underset{\text{Diglycyl Glycine.}}{NH_2CH_2CO.NHCH_2CO.NHCH_2COOH.}$$

The esters of the halogen acylamino-acids are easily converted by ammonia into dipeptide anhydrides, dioxopiperazines (see above).

(*b*) Again, the halogen-acyl-amino acids can be converted into their chlorides, united with other amino-acids and then be acted on by ammonia:

$$\underset{\text{Bromisocaproyl Glycine Chloride.}}{C_4H_9CHBrCO.NHCH_2COCl} \longrightarrow$$

$$\underset{\text{Bromisocaproyl Glycyl Glycine.}}{C_4H_9CHBrCO.NHCH_2CO.NHCH_2COOH} \xrightarrow{NH_3}$$

$$\underset{\text{Leucyl Glycyl Glycine.}}{C_4H_9CH(NH_2)CO.NHCH_2COOH.}$$

(*c*) Finally, the chlorides of the amino-carboxylic acid hydrochlorides can be employed with advantage (p. 383). The azides, also, of the acyl amino-acids such as hippuryl azide, $C_6H_5.CONHCH_2CON_3$, unite with amino-acids, splitting off N_3H, and easily forming *acyl derivatives* of the di- and polypeptides.

3. Higher polypeptides result from heating the methyl esters of lower peptides:

$$\underset{\text{Diglycyl Glycine Ester.}}{2NH_2CH_2CO.NHCH_2CO.NHCH_2CO_2CH_3} \longrightarrow \underset{\text{Pentaglycyl Glycine Ester.}}{NH_2CH_2CO.[NHCH_2CO]_4NHCH_2CO_2CH_3.}$$

4. Analytically, some di- and polypeptides have been produced by the *partial hydrolysis* of proteins, such as silk fibroïn, elastin, gliadine, gelatin, by means of cold fuming hydrochloric acid; or by tryptic digestion, as, for instance, glycyl alanine, alanyl leucine, alanyl diglycyl tyrosine (?) (B. **40,** 3544).

Properties.—Di- and polypeptides are mostly soluble in water; less soluble are, for instance, the penta- and hexa-peptides of glycocoll, which are, however, soluble in acids and alkalis, showing that the amino-acid character is preserved. The peptides are mostly insoluble in alcohol. They decompose, with or without melting, above 200°, the dipeptides forming mostly dioxo-piperazine.

The " biuret reaction "—a red or violet coloration with an alkaline solution of copper sulphate—which is characteristic for the naturally occurring proteïns, is given by many of the higher artificial peptides, such as *Curtius*' biuret base (triglycyl glycine ester).

The behaviour of di- and poly-peptides with *pancreatic* juice is of importance, since some are hydrolyzed by it and some are not, *e.g.* [*d*+*l*]-alanyl glycine is split up, yielding *d*-alanine and glycine, whilst glycyl alanine is not. All peptides are completely hydrolyzed by hydrochloric acid.

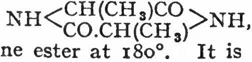
Glycyl Glycine, $NH_2CH_2CO.NHCH_2COOH$, decomposes 215–220°; *ethyl ester*, m.p. 89°, easily parts with alcohol, yielding

Glycine Anhydride, *Diglycolyl Diamide, αγ-Dioxopiperazine, αγ-Diacipiperazine,* $\overline{NHCH_2CO.NHCH_2CO}$, m.p. 275°, is also easily prepared from glycocoll ester in aqueous solution. By boiling for a short time with strong hydrochloric acid or by shaking with $n/_1$ sodium hydroxide, it is easily split up into *glycyl glycine* (B. **38,** 607). *Sarcosine Anhydride,* $CH_3\overline{NCH_2CON(CH_3)CH_2CO}$, m.p. 150°, b.p. 350°, is obtained by heating sarcosine (B. **17,** 286).

Glycyl [*d*+*l*]-*Alanine,* $NH_2CH_2CO.NHCH(CH_3)COOH$, m.p. 227° with decomposition, is prepared from chloracetyl alanine and ammonia; *anhydride,* m.p. 245° with decomposition, is formed from chloracetyl alanine ester and ammonia.

Glycyl d-Alanine and its *anhydride* are obtained by the hydrolysis of silk fibroïn (B. **40,** 3546). d-*Alanyl Glycine,* $CH_3CH(NH_2)CO.NHCH_2COOH$, m.p. 235° with decomposition, is produced from *d*-alanyl chloride hydrochloride and glycocoll ester (B. **38,** 2914).

Alanyl Alanine, $CH_3CH(NH_2)CO.NHCH(CH_3)COOH$, m.p. 276° with decomposition, is obtained by the decomposition by alkali of its *anhydride*. *Di-lactyl Di-amide, Lactimide,*



$NH\begin{matrix}<\end{matrix}\begin{matrix}CH(CH_3)CO\\CO.CH(CH_3)\end{matrix}\begin{matrix}>\end{matrix}NH$, m.p. 275°. The anhydride is best obtained from alanine ester at 180°. It is reduced by sodium and alcohol to βδ-dimethyl piperazine (B. **38,** 2376; C. 1902, I. 631). *l-Alanyl* d-*Alanine* is produced from *l*-bromopropionyl d-alanine and ammonia, $[\alpha]_D^{20} = -68{\cdot}5°$; its ester on parting with alcohol is converted into the optically inactive *meso-anhydride* (see Introduction, p. 32).

α-Aminobutyryl α-Aminobutyric Acid, $NH_2CH(C_3H_7)CO.NHCH(C_3H_7)COOH$, 2 stereoisomeric forms, m.p. 273° with decomposition, and m.p. 257° with decomposition, is prepared from bromobutyryl aminobutyric acid; *anhydride,* m.p. 267° (A. **340,** 187).

Leucyl Leucine, $NH_2CH(C_4H_9)CONHCH(C_4H_9)COOH$, m.p. 270° with decomposition, is formed from bromisocaproyl leucine and ammonia; *anhydride leucinimide,* m.p. 271°, is prepared from leucine ester (B. **37,** 2491).

Diglycyl Glycine, $NH_2CH_2CO.NHCH_2CO.NHCH_2COOH$, m.p. 246° with decomposition, is prepared from chloracetyl glycyl glycine and ammonia; *methyl ester,* m.p. 111°, when heated passes into *pentaglycyl glycine ester,* slightly soluble in water (B. **39** 472).

Triglycyl Glycine is prepared from chloracetyl diglycyl glycine; *ester*, $NH_2CH_2CO.NHCH_2CO.NHCH_2CO.NHCH_2COOC_2H_5$, the "biuret base," is formed together with a little glycine anhydride, when glycocoll is left to stand in solution in absolute ether. *Benzoyl Triglycyl Glycine*, m.p. 217°, is formed also from hippuryl glycine azide and glycyl glycine (B. **37**, 1284; 2486).

Leucyl Pentaglycyl Glycine, $C_4H_9CH(NH_2)CO[NHCH_2CO]_5NHCH_2COOH$, is prepared from bromisocaproyl pentaglycyl glycine and ammonia (B. **39**, 461).

β-AMINOCARBOXYLIC ACIDS

Of this group of substances little is known. They form neither cyclic double amides, as do the *a*-amino-acids, nor cyclic simple amides or lactams like the higher amino-acids, except betaïne.

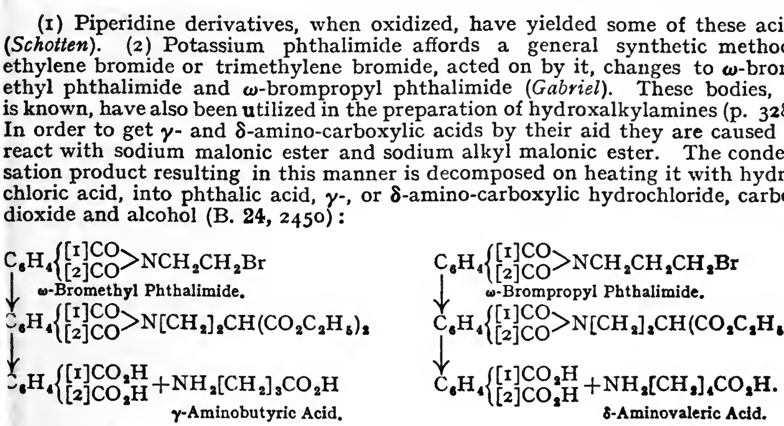
β-Aminopropionic Acid, β-Alanine, $CH_2(NH_2)CH_2.COOH$, m.p. 196° with decomposition into ammonia and acrylic acid. It is isomeric with alanine (p. 388), and is prepared from β-iodopropionic acid and ammonia, from β-nitropropionic acid, from isoserine (α-hydroxy- β-aminopropionic acid) by reduction with hydriodic acid and phosphorus (B. **35**, 3796); but most conveniently from succimide, $\begin{array}{l}CH_2.CO\\ |\\ CH_2.CO\end{array}\!\!>NH$, by the *Hofmann* inversion (p. 159) by means of bromine and alkali (B. **26**, R. 96; C. 1905, I. 155; 1906, I. 818); *methyl ester*, b.p.$_{15}$ 58°; *amide*, m.p. 40°; *β-Dimethylamine Propionic Methyl Ester*, $(CH_3)_2NCH_2\cdot CH_2COOCH_3$, b.p. 154°, is prepared from β-iodopropionic ester and dimethylamine. Heat partially transforms it into its isomer *β-Trimethyl Propiobetaïne*, $(CH_3)_3\overline{NCH_2CH_2COO}$, which in its turn undergoes transformation on melting into trimethylamine acrylate, $CH_2{:}CHCOONH(CH_3)_3$ (B. **35**, 584).

β-Aminobutyric Acid, $CH_3CH(NH_2)CH_2CO_2H$, m.p. 156° (approx.), is prepared by heating crotonic acid with ammonia. It is a very hygroscopic crystalline mass (J. pr. Ch. [2] **70**, 204). *β-Amino-isovaleric Acid*, $(CH_3)_2C(NH_2)CH_2COOH$, is produced by the reduction of the corresponding nitro-acid (p. 382).

γ-, δ-, ε-, and ζ-Aminocarboxylic Acids.

The most important characteristic of the γ- and δ-amino-carboxylic acids as well as of some of the higher acids is that when heated they part with water and yield cyclic, simple acid amides or lactams (p. 395).

(1) Piperidine derivatives, when oxidized, have yielded some of these acids (*Schotten*). (2) Potassium phthalimide affords a general synthetic method: ethylene bromide or trimethylene bromide, acted on by it, changes to ω-bromethyl phthalimide and ω-brompropyl phthalimide (*Gabriel*). These bodies, as is known, have also been utilized in the preparation of hydroxalkylamines (p. 328). In order to get γ- and δ-amino-carboxylic acids by their aid they are caused to react with sodium malonic ester and sodium alkyl malonic ester. The condensation product resulting in this manner is decomposed on heating it with hydrochloric acid, into phthalic acid, γ-, or δ-amino-carboxylic hydrochloride, carbon dioxide and alcohol (B. **24**, 2450):



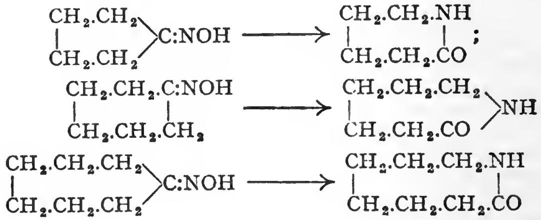
$$C_6H_4\left\{\begin{array}{l}[1]CO\\ [2]CO\end{array}\right.\!\!>NCH_2CH_2Br \quad \text{ω-Bromethyl Phthalimide.}$$
$$\downarrow$$
$$C_6H_4\left\{\begin{array}{l}[1]CO\\ [2]CO\end{array}\right.\!\!>N[CH_2]_2CH(CO_2C_2H_5)_2$$
$$\downarrow$$
$$C_6H_4\left\{\begin{array}{l}[1]CO_2H\\ [2]CO_2H\end{array}\right. + NH_2[CH_2]_3CO_2H \quad \text{γ-Aminobutyric Acid.}$$

$$C_6H_4\left\{\begin{array}{l}[1]CO\\ [2]CO\end{array}\right.\!\!>NCH_2CH_2CH_2Br \quad \text{ω-Brompropyl Phthalimide.}$$
$$\downarrow$$
$$C_6H_4\left\{\begin{array}{l}[1]CO\\ [2]CO\end{array}\right.\!\!>N[CH_2]_3CH(CO_2C_2H_5)_2$$
$$\downarrow$$
$$C_6H_4\left\{\begin{array}{l}[1]CO_2H\\ [2]CO_2H\end{array}\right. + NH_2[CH_2]_4CO_2H. \quad \text{δ-Aminovaleric Acid.}$$

Similarly, ε-bromo-amyl phthalimide can be made to yield ε-phthalimidoamyl malonic ester, and this converted into ζ-aminoheptylic acid (B. **35**, 1367).

Or, benzoyl amino-amyl iodide (p. 365) may easily be made to react with potassium cyanide or sodium malonic ester, the product from which is hydrolyzed.

(3) A general method for the preparation of δ-, ε-, and ζ-amino-acids and their lactams, is the transformation of the *oximes of cyclic ketones*, such as penta-, hexa-, and hepta-methylene ketoximes (Vol. II.). These are converted by concentrated sulphuric acid into *isoximes* or lactams (comp. *Beckmann's* inversion, p. 227) which can be decomposed into their respective amino-acids (*Wallach*, A. **312**, 171):



For considerations on the course of these transformations and on the *Beckmann* inversion generally, see A. **346**, 27.

γ-Aminobutyric Acid, *Piperidic Acid*, m.p. 183–184°. It is formed (1) when piperidyl urethane, $CH_2<\substack{CH_2CH_2\\CH_2CH_2}>N.CO_2C_2H_5$, is oxidized with nitric acid (B. **16**, 644); (2) by means of potassium phthalimide; either—(*a*) by the double decomposition of bromethyl phthalimide with sodium malonic ester (see above), or (*b*) from ω-bromopropyl phthalimide and potassium cyanide, and decomposing the phthalyl γ-aminobutyric nitrile (B. **23**, 1772). The acid is most conveniently obtained from its lactam (p. 395) by means of barium hydroxide solution (B. **33**, 2230). *γ-Dimethyl Aminobutyric Methyl Ester*, $(CH_3)_2N[CH_2]_3COOCH_3$, b.p. 172°, is prepared from γ-chlorobutyric ester and dimethylamine. On heating it is decomposed into butyrolactone and trimethylamine. The isomeric *γ-Trimethyl Butyrobetaïne*, $(CH_3)_3N[CH_2]_3COO$, which is obtained by exhaustive methylation of butyrolactam in alkaline solution (B. **35**, 617) undergoes the same decomposition.

γ-Aminovaleric Acid, $CH_3CH(NH_2)CH_2CH_2CO_2H$, m.p. 193°, results from the decomposition of phenylhydrazone lævulinic acid by sodium amalgam (B. **27**, 2313). Both γ-amino-acids, when heated, pass into lactams.

δ-Amino-n-Valeric Acid, *Homopiperidic Acid*, $NH_2(CH_2)_4CO_2H$, m.p. 158°, is produced by the putrescence of fibrin, flesh, and gelatin (B. **31**, 776).

The benzoyl derivative of this acid and also *Sulpho-δ-aminovaleric Acid*, $SO_2[NH(CH_2)_4CO_2H]_2$, m.p. 163°, are formed by the oxidation of benzoyl piperidine, $CH_2<\substack{CH_2CH_2\\CH_2CH_2}>NCOC_6H_5$, and of sulphopiperidine by $KMnO_4$ (B. **21**, 2240); the acid is prepared from phthalimido-propyl malonic diethyl ester (B. **23**, 1769).

By method 2 (p. 393) the following are also prepared: *α-Methyl δ-Amino*-n-*valeric Acid*, $NH_2.CH_2CH_2CH_2CH(CH_3)CO_2H$, m.p. 168°; *α-Ethyl δ-Amino*-n-*valeric Acid*, $NH_2CH_2CH_2CH_2CH(C_2H_5)CO_2H$, m.p. 200–200·5°; *α-Propyl δ-Amino*-n-*valeric Acid*, $NH_2CH_2CH_2CH_2CH(C_3H_7)CO_2H$, m.p. 186° (B. **24**, 2444). A *β*- or *γ-Methyl δ-Amino*-n-*valeric Acid*, m.p. 134°, with decomposition, is prepared from its lactam (p. 396) (A. **312**, 185).

δ-Trimethyl Valerobetaïne, $(CH_3)_3N[CH_2]_4COO$, of which the *hydrobromide* is obtained from γ-bromopropyl malonic esters and trimethylamine, by hydrolysis, and the action of hydrobromic acid. The substance itself is converted by heat into the isomeric *δ-Dimethylamine Valeric Methyl Ester*, $(CH_3)_2N[CH_2]_4COOCH_3$, b.p. 186–189°, together with δ-valerolactone (B. **37**, 1853).

δ-Amino-n-octanic Acid, *Homoconiinic acid*, $C_3H_7CH(NH_2)[CH_2]_3CO_2H$, m.p. 158°. The benzoyl compound is obtained by oxidation of benzoyl conine with $KMnO_4$ (B. **19**, 504).

ε-Aminocaproic Acid, *ε-Leucine*, $NH_2[CH_2]_5CO_2H$, m.p. 204°, is obtained from phthalimidobutyl malonic ester, from *ε-benzoyl aminocapronitrile*, $C_6H_5\text{-}CONH[CH_2]_5CN$ (B. **40**, 1839), or from its lactam, the hexamethylene ketone-isoxime, by boiling with hydrochloric acid. Similarly, various acids can be prepared from their lactams, such as *methyl ε-aminocaproic acid* and *methyl isopropyl ε-aminocaproic acid*. ε-Aminocaproic acid is oxidized by permanganate to adipic acid; nitrous acid produces two isomeric hexenic acids instead of the expected ε-hydroxycaproic acid (p. 375) (A. **343**, 44).

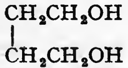
ζ-Amino-n-heptylic Acid, $NH_2[CH_2]_6COOH$, m.p. 187° with decomposition, is also prepared from its lactam, the isosuberone oxime (*q.v.*); also from the phthalimido-amyl malonic ester, or benzoyl amyl aminomalonic ester (B. **40**, 1840). On heating, it no longer yields a simple lactam (B. **35**, 1369). Permanganate oxidizes it to pimelic acid (A. **343**, 44).

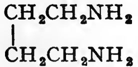
10-*Aminocapric Acid*, $NH_2[CH_2]_9COOH$, m.p. 188°, is prepared from azelaïc monoamido-acid, $NH_2CO[CH_2]_7COOH$, and alkali hypobromite; *benzoyl derivative*, m.p. 97°. These products are not identical with those obtained from benzoyl dekamethylene imine (p. 365) by oxidation (C. 1906, II. 1126).

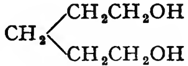
γ-, δ-, ε-, and ζ-Lactams: Cyclic Amides of the γ-, δ-, ε-, and ζ-Amino-carboxylic Acids.

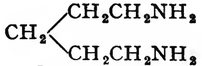
These bodies are formed when the γ-, δ-, and ε-amino-acids are heated to their point of fusion, when they then lose water, and undergo an intramolecular condensation. Some of them have been obtained by the reduction of the anil chlorides of dibasic acids—*e.g.* succinimide and dichloromaleïn anil chloride. The names γ-lactams and δ-lactams have been given them to recall the lactones. They are cyclic acid-amides. Just as the lactones, under the influence of the alkali hydroxides, yield hydroxy-acid salts, so the lactams, when digested with alkalis or acids, pass into salts of the amido-acids, from which they can be formed on the application of heat.

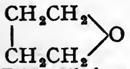
Further, the γ- and δ-lactams bear the same relation to the imides of the γ- and δ-alkylene diamines as the lactones to the oxides of the γ- and δ-glycols (p. 371). These relations are apparent in the following arrangement:

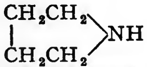

$$\begin{array}{l}CH_2CH_2OH\\ |\\ CH_2CH_2OH\end{array}$$
Tetramethylene Glycol.

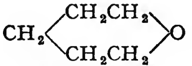

$$\begin{array}{l}CH_2CH_2NH_2\\ |\\ CH_2CH_2NH_2\end{array}$$
Tetramethylene Diamine.

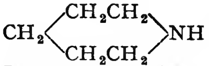

Pentamethylene Glycol.

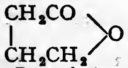

Pentamethylene Diamine.

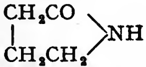

Tetramethylene Oxide, Tetrahydrofurfurane.

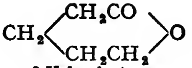

Tetramethylene Imine, Tetrahydropyrrol.

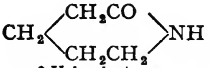

Pentamethylene Oxide.

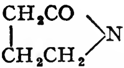

Pentamethylene Imine, Piperidine.

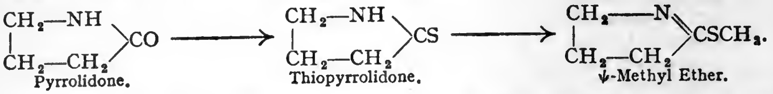

γ-Butyrolactone.


γ-Butyrolactam, α-Pyrrolidone.


δ-Valerolactone.


δ-Valerolactam, α-Piperidone.

γ-Lactams: *γ-Butyrolactam, α-Pyrrolidone,*  $\left.\begin{array}{l}CH_2CO\\ |\\ CH_2CH_2\end{array}\right\rangle NH$, m.p. 25°, b.p. 245°, unites with water to form a crystalline hydrate, $C_4H_7ON+H_2O$, m.p. 35°. It is best prepared from succinimide by electrolytic reduction (B. 33, 2224). *Isopropyl pyrrolidone*, $C_4H_6ON.C_3H_7$, b.p. 222°, is similarly prepared from isopropyl-succinimide, and n-*Phenyl Butyrolactam*, $C_4H_6ON.C_6H_5$, from succinanil. It can also be produced by reduction of dichloromaleïn anil dichloride (A. **295**, 27). Pyrrolidone possesses feebly basic and acid properties. Its sodium salt reacts with iodomethane, producing n-methyl pyrrolidone, $C_4H_6O.NCH_3$, an oil. When boiled with P_2S_5 in xylol, pyrrolidone is converted into *Thiopyrrolidone*, C_4H_7SN, the potassium salt of which, with iodomethane, gives *Thiopyrrolidone ψ-Methyl Ether*, b.p. 170° (B. **40**, 2831, 2848):


Pyrrolidone. Thiopyrrolidone. ψ-Methyl Ether.

The ψ-methyl ether, on reduction, breaks up into methyl mercaptan and pyrrolidine (p. 335).

γ-Valerolactam, δ-Methyl Pyrrolidone, $\left.\begin{array}{l}CH_2-CH(CH_3)\\ \vert\\ CH_2-\!\!-\!\!-\!\!-CO\end{array}\right>NH$, m.p. 37°, can be distilled without decomposition. By reduction with sodium and amyl alcohol it is changed into α-methyl pyrrolidine (p. 335) (B. **23**, 1860, 2364, 3338; **23**, 708). *ββ-Dimethyl Pyrrolidone, αα-Dimethyl Butyrolactam*, $\left.\begin{array}{l}CH_2-CH_2\\ \vert\\ C(CH_3)_2CO\end{array}\right>NH$, m.p. 66°, b.p. 237° (C. 1899, I. 874).

δ-Lactams: *δ-Valerolactam, α-Ketopiperidine, α-Oxopiperidine, α-Piperidone*, $CH_2{<}\begin{array}{l}CH_2.CO\\ CH_2.CH_2\end{array}{>}NH$, m.p. 39–40°, b.p. 256°, is obtained, amongst other methods, by the isomerization of cyclopentanone oxime (A. **312**, 179). *α-Methyl δ-Valerolactam, β-Methyl Piperidone*, $CH_2{<}\begin{array}{l}CH(CH_3)CO\\ CH_2-CH_2\end{array}{>}NH$, m.p. 55°, is isomeric with the *β-* or *γ-Methyl Piperidone*, m.p. 87°, obtained from β-methyl cyclopentanone oxime (A. **312**, 186). *α-Ethyl δ-Valerolactam, β-Ethyl Piperidone*, $CH_2{<}\begin{array}{l}CH(C_2H_5)CO\\ CH_2-\!\!-\!\!-CH_2\end{array}{>}NH$, m.p. 68°, b.p.$_{42}$ 141° (B. **23**, 3694). *α-Propyl δ-Valerolactam, β-Propyl Piperidone*, $CH_2{<}\begin{array}{l}CH(C_3H_7)CO\\ CH_2-\!\!-\!\!-CH_2\end{array}{>}NH$, m.p. 59°, b.p. 274°. *δ-n-Octanolactam, Homoconiinic Acid Lactam*, $CH_2{<}\begin{array}{l}CH_2CO\\ CH_2.CH-C_3H_7\end{array}{>}NH$, m.p. 84°.

The amino-acids are not poisonous, but their γ- and δ-lactams are violent, strychnine-like poisons, affecting the spinal cord and producing convulsions. These bodies will be met with again among the pyrrole and pyridine derivatives, as tetrahydropyrrole and piperidine compounds (Vol. II.).

ε-Caprolactam, $\left.\begin{array}{l}CH_2.CH_2.CO\\ \vert\\ CH_2.CH_2CH_2\end{array}\right>NH$, m.p. 69°, is obtained by the transformation of cyclohexanone oxime (A. **312**, 187); and from ε-aminocaproic acid (p. 394). It acts, physiologically, as a nerve poison. β-Methyl cyclohexanone oxime and also oximes of the terpene ketones menthone and tetrahydrocarvone can be converted into two *methyl ε-caprolactams*, m.ps. 44° and 105° (structure, A. **346**, 253) and two isomeric *methyl isopropyl ε-caprolactams, menthone isooxime*, m.p. 120°, and *tetrahydrocarvone isooxime*, m.p. 104° (A. **312**, 197, 203).

ζ-Heptolactam, $\begin{array}{l}CH_2.CH_2.CH_2.NH\\ \vert\qquad\qquad\quad\ \vert\\ CH_2.CH_2.CH_2CO\end{array}$, m.p. 25°, b.p.$_8$ 156°, is prepared from heptamethylene ketoxime or suberone oxime. It can be broken down into ζ-aminoheptylic acid (p. 395), which on warming with nitrous acid is converted into εζ-heptylenic acid (A. **312**, 205).

11. **Fatty Acid Nitramines,** *Nitramine Acetic Acid*, $CO_2HCH_2.NHNO_2$, m.p. 103°, is prepared by hydrolyzing its ethyl ester (m.p. 24°), which results on treating nitrourethane acetic ester, $C_2H_5O_2C.N(NO_2).CH_2CO_2C_2H_5$, with ammonia (B. **29**, 1682).

12. **Isonitramine Fatty Acids** are obtained in the form of their sodium salts when sodium isonitramine acetoacetic esters and sodium isonitramine mono-alkyl acetoacetic esters, or the explosive dinitroso-compounds of the hydrazo-fatty acids, such as hydrazoisobutyric acid (p. 416), are acted on by

the alkalis (B. **29**, 667; A. **300**, 64). They are converted into hydroxylamino-fatty acids by dilute mineral acids (p. 381). Acid reducing agents change them to amino-fatty acids, whilst alkaline reducing agents produce diazo-acids (p. 402) and hydrazino-acids (see below).

Isonitramine Acetic Acid, $CO_2HCH_2N{<}\begin{smallmatrix}NO\\OH\end{smallmatrix}$, is a syrupy liquid. *Isonitramine Isobutyric Acid,* $CO_2HC(CH_3)_2.N(NO)OH$, m.p. 94°. Their lead salts dissolve with difficulty.

13 (*a*). **Hydrazino-fatty Acids** are obtained, together with the diazo-acids, when the isonitramine-fatty acids are acted on with alkaline reducing agents. Their carbamide derivatives are obtained in the form of nitriles when hydrocyanic acid becomes added to the ketone semicarbazides. *Hydrazino-acetic Acid,* $NH_2NH.CH_2COOH$, m.p. 152°, with decomposition (B. **31**, 164). (See also Amidohydantoïne Acid Ester and Carbamidohydrazo-acetic Ester.)

α-Hydrazinopropionic Acid, Amino-alanine, $NH_2NH.CH(CH_3)CO_2H$, m.p. 180°, is formed from α-isonitramine propionic acid (B. **29**, 670), and from the addition product of hydrocyanic acid and acetaldehyde semicarbazone (A. **303**, 79). *α-Hydrazinobutyric Acid,* $NH_2NH.C(CH_3)_2CO_2H$, m.p. 237° with decomposition. It is formed when steam acts on its benzal derivative. The latter is made by acting on acetone semicarbazide, $NH_2CONHN{=}C(CH_3)_2$, with hydrocyanic acid, when carbamido-hydrazino-isobutyronitrile is produced. This is then decomposed with hydrochloric acid, and benzaldehyde is added (A. **290**, 15).

13 (*b*). **Hydrazo-fatty Acids.**—When a hydrazino-fatty acid is treated with acetone and potassium cyanide, a hydrazo-nitrile acid results: thus, from α-hydrazino-isobutyric acid we get *Hydrazo-isobutyronitrilic Acid,* $\begin{smallmatrix}(CH_3)_2\\HO_2C\end{smallmatrix}{>}C.NHNH.C{<}\begin{smallmatrix}(CH_3)_2\\CN\end{smallmatrix}$, m.p. 100°. When hydrazine sulphate (1 mol.), acetone (2 mols.), and potassium cyanide (2 mols.) react, the product is *Hydrazo-isobutyronitrile,* $\begin{smallmatrix}(CH_3)_2\\NC\end{smallmatrix}{>}C.NH.NH.C{<}\begin{smallmatrix}(CH_3)_2\\CN\end{smallmatrix}$, m.p. 92°. Hydrochloric acid converts both nitriles into *Hydrazo-isobutyric Acid,* $\begin{smallmatrix}(CH_3)_2\\HOOC\end{smallmatrix}{>}C.NHNH.C{<}\begin{smallmatrix}(CH_3)_2\\COOH\end{smallmatrix}$, m.p. 223°.

Its dinitroso-compound is decomposed by alkalis into isonitramine isobutyric acid (see above), α-hydroxy-isobutyric acid and nitrogen (A. **300**, 59).

14. **Azo-fatty Acids.**—Bromine water oxidizes hydrazo-esters and hydrazonitriles to the corresponding azo-bodies. **Azo-isobutyronitrile,** $\begin{smallmatrix}(CH_3)_2\\NC\end{smallmatrix}{>}C.N{:}N.C{<}\begin{smallmatrix}(CH_3)_2\\CN\end{smallmatrix}$, m.p. 105°, when heated alone, or, better, with hot water, passes into tetramethyl succinic nitrile (A. **290**, 1).

B. UNSATURATED HYDROXY-ACIDS, HYDROXY-OLEFINE CARBOXYLIC ACIDS

α-Hydroxy-olefine Carboxylic Acids are obtained by the action of cold hydrochloric acid on the nitriles, the addition products of hydrocyanic acid and olefine-aldehydes.

Vinyl Glycollic Acid, $CH_2{:}CHCH(OH)COOH$, m.p. 33°, b.p. 129°, is prepared from its *nitrile, acroleïn cyanhydrin,* $b.p._{17}$ 94°, or the *amide,* m.p. 86°, $b.p._{21}$ 155–158°. When heated with acids it is partly converted into an α-ketone-acid—propionyl formic acid, $CH_3CH_2CO.COOH$. This also results, together with various condensation products, when vinyl glycollic acid is acted on by alkalis (Rec. trav. Chim. **21**, 209).

Propenyl Glycollic Acid, α-Hydroxypentenic Acid, $CH_3CH{:}CHCH(OH)COOH$, is obtained from crotonaldehyde cyanhydrin. Boiling dilute acids convert it directly into an αγ-keto-acid—lævulinic acid (B. **29**, 2582):

$$CH_3CH{:}CH.CH(OH)COOH \longrightarrow CH_3CO.CH_2CH_2COOH.$$

α-Ethoxy-acrylic Acid, $CH_2{:}C(OC_2H_5).CO_2H$, m.p. 62°, is obtained by hydrolysis of its *ethyl ester,* b.p. 180° (comp. Acetal of Pyroracemic Ester, p. 408) (B. **31**, 1020).

β-Hydroxy-olefine Carboxylic Acids are obtained by condensation of olefine aldehydes with α-halogen-fatty esters by means of zinc (comp. mode of formation

12*a*, p. 358). When an available hydrogen atom is present in the α-position, these acids readily lose water, as when, for instance, they are boiled with sodium hydroxide, forming di-olefine carboxylic acids (B. **35**, 3633, C. 1903, 555; 1906, II. 318):

$$CH_3CH:CH.CHO \xrightarrow[Zn]{Br.CH_2CO_2R} CH_3CH:CH.CH(OH)CH_2CO_2R$$

β-Hydroxy-hydrosorbic Acid.

$$\longrightarrow CH_3CH:CH.CH:CHCO_2H.$$

Sorbic Acid.

β-Hydroxy-hydrosorbic Acid is an oil, slightly soluble in water; *ethyl ester*, b.p.$_2$ 100°. *α-Methyl Hydroxy-hydrosorbic Ester*, b.p.$_{15}$ 111°. *α-Ethyl β-Hydroxy sorbic Ester*, b.p.$_{15}$ 111°. *α-Ethyl β-Hydroxy-hydrosorbic Ester*, $CH_3CH:CHCH(OH)C(CH_3)_2CO_2R$, b.p.$_{17}$ 119°, is stable. *α-Dimethyl β-Vinyl Hydracrylic Acid, Vinyl Hydroxypivalic Acid*, $CH_2:CH.CH(OH)C(CH_3)_2CO_2H$, b.p.$_{23}$ 159°; *ethyl ester*, b.p.$_{19}$ 106°, is prepared from acroleïn bromisobutyric ester and zinc. In benzene solution, P_2O_5 causes the splitting off of water, and simultaneously the addition of benzene, forming the compound $C_6H_5.CH_2CH:CHC(CH_3)_2CO_2R$.

β-Hydroxy-acrylic Acid, $CH(OH):CHCO_2H$, and **β-Hydroxycrotonic Acid**, $CH_3C(OH):CH.CO_2H$. Both these acids and their homologues are the starting points for the *aci-forms* (p. 40) of the *β-aldo-* and *β-keto-carboxylic acids*, such as formyl acetic ester and acetoacetic ester:

aci-form	$CH(OH):CHCO_2C_2H_5$	$CH_3C(OH):CH.CO_2C_2H_5$
keto-form	$CHO.CH_2CO_2C_2H_5$	$CH_3CO.CH_2CO_2C_2H_5$.
	Formyl Acetic Ester.	Acetoacetic Ester.

In the free state formyl acetic ester exists as β-hydroxy-acrylic ester (*aci*-modification), whilst acetoacetic ester is more stable in the keto-form. Since the *aci-* or *enol*-form is usually looked on as being a subsidiary form, and the *aldo-* or *keto*-form, the fundamental modification, those derivatives, such as *β-alkoxy-* and *β-acyloxy*-olefine carboxylic acids, which are undoubtedly of the enol-form, will be described with the latter.

γ- and **δ-Hydroxy-olefine Carboxylic Acid** are known in the form of their lactones, of which some are obtained by distillation of the γ-keto acids, and others from βγ-dibromo- or dichloro-fatty acids with the loss of 2 molecules of halogen acid. These Δ^1- and Δ^2-lactones are changed back into γ-keto- or aldehyde acids by hydrolysis.

Δ^2-Butene Lactone, Crotolactone, $\overline{CH:CH.CH_2COO}$, m.p. 4°, b.p.$_{15}$ 96°, is formed from βγ-dichlorobutyric acid when heated alone or with potassium carbonate (C. 1905, II. 45; B. **35**, 9422).

γ-Ethoxycrotonic Acid, $C_2H_5OCH_2CH:CHCOOH$, m.p. 45°, b.p.$_{26}$ 148°, is obtained from γ-ethoxy-β-hydroxybutyronitrile, the addition product of hydrocyanic acid to epiethylin, $C_2H_5OCH_2\overline{CH.CH_2O}$ (C. 1905, I. 1138).

Δ^2-Angelic Lactone, $CH_3\overline{C{=}CHCH_2COO}$, m.p. 18°, b.p. 167°, and *Δ^1-Angelic Lactone*, $CH_3\overline{CH.CH.CHCOO}$, b.p.$_{25}$ 83°, are prepared from lævulinic acid and acetyl lævulinic acid. The Δ^2-lactone can be formed from the Δ^1-lactone by various methods; the change is, however, reversible. The Δ^2-lactone, in contradistinction to the Δ^1-lactone, can be condensed with aldehydes at the α-CH_2 group (A. **319**, 180).

Mesitonic acid (αα-dimethyl lævulinic acid, p. 423) gives rise to *α-Dimethyl Δ^1-Angelic Lactone*, m.p. 24°, b.p. 167°. The isomeric *ααβ-trimethyl-Δ^2-butero-lactone* is prepared from the corresponding *dibromo-acid*. *Iso-octenolactone*, $(CH_3)_2CHCH_2\overline{CH.CH:CH.COO}$, is obtained from iso-octenic acid dibromide (C. 1905, II. 457; A. **347**, 132).

γ-Methyl- and *γ-Ethyl-αβ-dichloro-* and *-αβ-dibromo-butene Lactone* $R.\overline{CH.CX:CXCOO}$, b.p.$_{22}$ 120°, b.p.$_4$ 110°; m.p. 69°; m.p. 51°, are prepared from mucochloric acid and mucobromic acid (p. 402) by means of magnesium alkyl halides (B. **38**, 3981).

Parasorbic Acid, or *Sorbin Oil,* $CH_3CH_2CHCH{:}CHCOO$, or CH_3-$CHCH_2CH{:}CHCOO$, b.p. 221°, occurs, together with malic acid, in the juice of ripe and unripe mountain ash berries (*Sorbus aucuparia*). It is optically active: $[\alpha]_j = +40{\cdot}8$, and is a strong emetic. It passes into sorbic acid (p. 305) when heated with sodium hydroxide or hydrochloric acid (B. **27**, 344).

Di-olefine δ-lactones have been obtained from *coumalic acid* and *isodehydracetic acid* by the splitting-off of carbon dioxide:

Coumalin, $CH{=}CH{-}CH{=}CH.COO$, m.p. 5°, b.p.$_{30}$ 120°, has an odour like that of coumarin (A. **264**, 293).

Mesitene Lactone, βδ-Dimethyl Coumalin, $CH_3C{=}CH{-}C(CH_3){=}CH.COO$, m.p. 51·5°, b.p. 245°. When heated with ammonia it changes to the corresponding lactam, so-called *pseudo-lutidostyril, mesitene lactam* (below).

Diallyl Butyrolactone, $(CH_2{:}CHCH_2)CCH_2CH_2COO$, b.p. 267°, is prepared from succinic ester, allyl iodide, and zinc (comp. the general method of formation of tert.-α-hydroxy-acid esters from oxalic ester, alkyl halides, and zinc, p. 358) (J. pr. Ch. [2] **71**, 249).

Ricinoleic Acid, $C_{18}H_{34}O_3$, is an unsaturated hydroxy-carboxylic acid (p. 302).

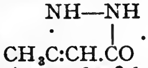
NITRO- AND AMINO-OLEFINE CARBOXYLIC ACIDS

α-Nitro-dimethyl Acrylic Acid, $(CH_3)_2C{:}C(NO_2)COOH$. Its *ester,* b.p.$_{24}$ 121°, is prepared by nitrating dimethyl acrylic ester (p. 299) with fuming nitric acid. Alcoholic potassium hydroxide converts it into the potassium salt of an *isomeric nitro-acid ester,* $\genfrac{}{}{0pt}{}{CH_3}{CH_2}{\gg}C.CH(NO_2)COOC_2H_5$; ammonia decomposes it into acetone and nitro-acetic ester (p. 380); reduction with aluminium amalgam produces nitrodimethyl acrylic ester.

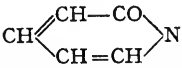
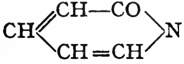
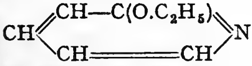
α-Aminodimethyl Acrylic Acid Ester, $(CH_3)_2C{:}C(NH_2)COOC_2H_5$, b.p.$_{18}$ 94°, is converted by hydrochloric acid into dimethyl pyroracemic acid (p. 408).

β-Amino-acids and β-Hydrazino Olefine Carboxylic Acids.

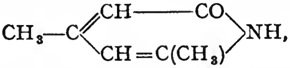
This group contains the reaction-products of ammonia and the hydrazines on β-ketone-acid esters such as acetoacetic esters and alkyl acetoacetic esters. Thus,

β-Aminocrotonic Ester, $CH_3C(NH_2){:}CH.CO_2C_2H_5$, is produced; also, *Methyl Pyrazolone,*  $\begin{matrix}NH{-}NH\\ \cdot\quad|\\ CH_3C{:}CH.CO\end{matrix}$. This behaves desmotropically, and because of its close connection to the β-ketone-acid esters will be considered with them (p. 418).

δ-Diolefine Lactams.

α-Pyridone, *δ-Aminopentadiene Acid Lactam,* , m.p. 106°, is obtained from the reaction-product of ammonia and coumalic acid after the elimination of carbon dioxide (B. **18**, 317). It can be converted into the odourless *Ethylimide,* , b.p. 258°, and *α-Ethoxypyridine,* , b.p. 156°, which possesses an odour like that of pyridine (B. **24**, 3144) (see Vol. II.).

Pseudolutidostyril, [3,5]-Dimethyl α-Pyridone, Mesitene Lactam,



m.p. 180°, b.p. 305°, is formed when ammonia acts on mesitene lactone, and from the two monocarboxylic acids of this lactam by the elimination of CO_2 (A. **259**, 168).

8. ALDEHYDE-ACIDS

These are bodies which show both the properties of a carboxylic acid and of an aldehyde. Formic acid is the simplest representative of the class, and it is also the first member of the homologous series of saturated aliphatic monocarboxylic acids. But it and its derivatives have been, with repeated reference to its aldehydic nature, discussed before acetic acid and their higher homologues. The best known aldehyde carboxylic acid, a compound of the aldehyde group CHO with the carboxyl group COOH, is glyoxylic acid, which is an oxidation product of ethylene glycol.

I. **Glyoxylic Acid**, *Glyoxalic Acid* [Ethanal Acid] $(HO)_2.CH.CO_2H$ or $OCH.CO_2H+H_2O$, was found by *Debus* (1856) among the products resulting from the oxidation of alcohol with nitric acid. It occurs in unripe gooseberries and other fruit, from which it disappears on the fruit ripening. Its formation and reactions are of significance in plant physiology (B. **25,** 800; **35,** 2446; **40,** 4943). Just as chloral hydrate is to be considered as trichlorethidene glycol, $CCl_3CH(OH)_2$, so crystallized glyoxylic acid can be regarded as the glycol corresponding with the aldehydo-acid, $CHO.CO_2H$. All the salts are derived from the dihydroxyl formula of glyoxylic acid; hence it may be designated *dihydroxy-acetic acid.* Like chloral hydrate, glyoxylic acid in many reactions behaves like a true aldehyde (B. **25,** 3425).

Methods of Formation.—Glyoxalic acid results (1) from the oxidation of alcohol (B. **27,** R. 312), aldehyde and glycol, and is accompanied by glyoxal (p. 346) and *glycollic acid* (p. 362); (2*a*) by heating dichlor- and dibromacetic acid to 230° with water (B. **25,** 714); (2*b*) by boiling silver dichloracetate with water (B. **14,** 578); (2*c*) the best method is by the action of potassium acetate on dichloracetic acid, producing *diacetyl dihydroxyacetic acid* $(CH_3COO)_2CHCOOH$, which on boiling with water yields glyoxylic acid (A. **311,** 129).

(3) From hydrazi-acetic acid (p. 405).

(4) It is formed direct by reduction of oxalic acid and its ester (comp. also Glycollic acid, p. 362).

(*a*) Electrolytic reduction of oxalic acid in sulphuric acid and with mercury cathode gives an 87 per cent. yield of glyoxylic acid (B. **37,** 3187):

$$COOH.COOH+H_2=COOH.CH(OH)_2.$$

(*b*) A similar reduction of oxalic ester produces glyoxylic ester (B. **37,** 3591).

(*c*) Reduction of oxalic ether with sodium amalgam in alcohol produces the alcoholate of glyoxylic ester, together with ketomalonic ester, desoxalic ester, and racemic ester (B. **40,** 4942).

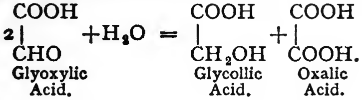
Properties.—It is a thick liquid, readily soluble in water, and crystallizes in rhombic prisms by long standing over sulphuric acid. The crystals have the formula $C_2H_4O_4$ (see above). It distils undecomposed with steam.

Salts.—The salts contain water of crystallization which, on being dried, give it up with partial decomposition. The *calcium salt,* $(C_2H_3O_3)_2Ca+2H_2O$, is sparingly soluble in water (A. **317,** 147; C. 1904, II. 1705).

Esters: Glyoxylic Ethyl Ester, $CHO.COOC_2H_5$, b.p. 130°, an easily polymerized substance, is produced by the electrolytic reduction of oxalic ether, and also from its *alcoholate*, $C_2H_5OCH(OH)CO_2C_2H_5$, b.p. 137°, by the action of P_2O_5. This substance is prepared by the reduction of the oxalic ether with sodium amalgam (see above). Alcohol and hydrochloric acid produce *Di-ethoxyacetic Ester*, $(C_2H_5O)_2CHCO_2C_2H_5$, b.p. 199°, which, on hydrolysis, yields *di-ethoxy-acetic acid*. Glyoxylic ethyl ester develops a bright coloration with ammonia and methylamine in presence of air (C. 1906, I. 1654; B. **40**, 4953). *Glyoxylic Methyl Ester*, m.p. 53° (B. **37**, 3591). Hydrazines, hydroxylamine, etc., give typical aldehyde derivatives with the esters (C. 1907, I. 401).

Reactions.—Glyoxylic acid exhibits all the properties of an aldehyde. It reduces ammoniacal silver solutions with formation of a mirror, and combines with primary alkali sulphites (p. 195), with phenylhydrazine (B. **17**, 577), with hydroxylamine, thiophenol and hydrochloric acid (B. **25**, 3426). When oxidized (silver oxide), it yields oxalic acid; by reduction it forms glycollic acid and racemic acid, $CO_2HCH(OH).CH(OH)COOH$. On boiling the acid with alkalis, glycollic and oxalic acids are produced (B. **13**, 1931).

This reaction is extramolecular, and completes itself by the intramolecular rearrangement of the glyoxal, under like conditions, into glycollic acid:



$$2\begin{array}{l}COOH\\|\\CHO\end{array} + H_2O = \begin{array}{l}COOH\\|\\CH_2OH\end{array} + \begin{array}{l}COOH\\|\\COOH.\end{array}$$

Glyoxylic Acid. Glycollic Acid. Oxalic Acid.

The formation of glycollic and tartaric acids also occurs when glyoxylic acid is carefully heated (C. 1904, II. 1705); they are also formed by the interaction of glyoxylic, hydrocyanic, and hydrochloric acids. Ammonia causes the elimination of CO_2 and the formation of formyl glycocoll (p. 388), and ultimately glycocoll (B. **35**, 2438). For the change of glyoxylic acid by urea into allantoïn (see p. 573).

II. **β-Aldo-carboxylic Acids**, $HOC.CHR.CO_2H$, and their esters exhibit reactions of *aci*-form compounds and behave as *β-hydroxy-△′-olefine carboxylic acids*, $HOCH : CRCO_2H$ (pp. 397, 398), in which form they are most favourably constituted to yield esters.

Formyl Acetic Acid, *β-Aldopropionic Acid* (*half aldehyde of malonic acid*), $CHO.CH_2COOH$ or $CH(OH) : CHCO_2H$, appears to be formed by the hydrolysis of its *acetal*, *Di-ethoxypropionic acid*, $(C_2H_5O)_2CHCH_2COOH$. This is obtained by oxidation of β-hydroxypropionacetal (p. 338) (B. **33**, 2760); *ethyl ester*, b.p. 193°; and also from orthoformic ester (p. 246), bromacetic ester and zinc (J. pr. Ch. [2] **73**, 326):

$$HC(OC_2H_5)_3+BrZnCH_2COOC_2H_5=HC(OC_2H_5)_2.CH_2CO_2C_2H_5+C_2H_5OZnBr.$$

It readily loses alcohol, forming the ester of *β-Ethoxyacrylic Acid*, $C_2H_5OCH:$-$CHCOOH$, m.p. 110°. This readily decomposes into CO_2 and acetaldehyde, probably with the intermediate formation of formyl acetic acid.

Formyl Acetic Ester, *Hydroxymethylene Acetic Ester*, *β-Hydroxyacrylic Ester*, $(C_2H_3O)CO_2R$, is obtained in the form of its *sodium* compound, $NaOCH : CHCO_2R$, by the condensation of formic and acetic esters by means of sodium in benzene or ethereal solution:

$$HCOOC_2H_5+CH_3COOC_2H_5+Na=NaOCH:CHCOOC_2H_5+HOC_2H_5.$$

The free ester is easily condensed to *formyl glutaconic ester*, $HC(OH) : C(CO_2R)$-$CH : CH.CO_2R$, and *trimesic ester*, $C_6H_3(CO_2R)_3$. Concentrated sulphuric acid produces coumalic acid (*q.v.*). Acetyl chloride and sodium formyl acetic ester form an *acetate*, $CH_3CO.OCH : CHCO_2C_2H_5$, $b.p._{46}$ 126°. This takes up 2 atoms of bromine producing a *dibromide*, $b.p._{34}$ 154°, which indicates the structure of the acetate (B. **25**, 1046). Nitrobenzoyl chloride produces *two stereoisomeric nitrobenzoates* (A. **316**, 18). *Cyanacetaldehyde*, *Hydroxymethylene Acetonitrile*, $(C_2H_3O)CN$, is produced as a sodium salt from isoxazole and sodium ethoxide (p. 354).

α-Formyl Propionic Acid, $OCHCH(CH_3)CO_2H$ or $CH(OH) : C(CH_3)CO_2H$; *acetal*, $(C_2H_5O)_2CH.CH(CH_3)CO_2H$, of which the ester is prepared from orthoformic ester and α-bromozinc propionic acid, easily breaks down into alcohol and *β-Ethoxymethyl Acrylic Acid*, $C_2H_5OCH : C(CH_3)CO_2H$, m.p. 109°. This is formed from bromo-methyl-acrylic acid and sodium alcoholate. It readily decomposes into CO_2, propionaldehyde and alcohol (B. **39**, 3549). *α-Formyl Propionic Ester, α-Hydroxymethylene Propionic Ester*, $HOCH : C(CH_3)CO_2C_2H_5$, b.p. 161°; *acetate*, $b.p._{48}$ 132° (A. **316**, 333).

III. γ- and δ-**Aldo-carboxylic Acids.**

β-Formyl Propionic Acid, γ-Aldobutyric Acid (*half aldehyde of succinic acid*), $CHO.CH_2.CH_2CO_2H$, is produced from acetal malonic acid $(C_2H_5O)_2CH.CH_2CH(CO_2H)_2$, when the latter is heated with water to 190°; or, better, by boiling aconic acid (*q.v.*) in water, when CO_2 is given off (B. **37**, 1801). It forms crystals, soluble in water. When evaporated with sodium hydroxide solution, it yields a small quantity of terephthalic acid (Vol. II.); reduction converts it into butyrolactone. Its *nitrile* serves for the derivation of *β-cyanopropionacetal*, $CNCH_2CH_2CH(OC_2H_5)_2$, $b.p._{45}$ 106°, the reaction product of γ-chloropropionacetal and KNC (B. **34**, 1924). *β-Formyl Isobutyric Acid, α-Methyl β-Aldobutyric Acid*, $CHO.CH_2CH(CH_3)CO_2H$ (C. 1899, I. 557).

δ-Aldovaleric Acid, γ-Formyl Butyric Acid (*half aldehyde of glutaric acid*), $CHO.CH_2CH_2CH_2COOH$, b.p. 240°, is prepared from β-propionacetal malonic ester by hydrolysis and the loss of CO_2 (B. **38**, 2884); by boiling the ozonide of cyclopentene (Vol. II.) with water, associated with *Glutaric Dialdehyde*, $b.p._{10}$ 71° (p. 347) and glutaric acid (B. **41**, 1706). *δ-Formyl γ-Methyl Valeric Acid*, $HOC.CH(CH_3)CH_2CH_2COOH$, $b.p._{12}$ 154°, is obtained by the oxidation of citronellal acetal (p. 215) with permanganate (B. **34**, 1498).

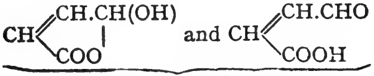
IV. **Aldo-olefine Carboxylic Acids.**

β-Formyl Acrylic Acid (*half aldehyde of maleïc acid*), CHOCH : CHCOOH, m.p. 55°, $b.p._{10}$ 145°, is produced by the oxidation of pyromucic acid (Vol. II.) by bromine and alkali. It is converted into succinic acid when heated with a solution of potassium cyanide (B. **38**, 1272):

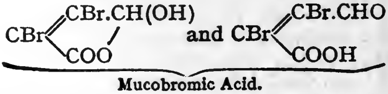
$$\underset{\text{Pyromucic Acid.}}{OCH{:}CH.CH{:}CCO_2H} \xrightarrow{O} \underset{\beta\text{-Formyl Acrylic Acid.}}{CHO.CH{:}CHCO_2H} \xrightarrow{H_2O} \underset{\text{Succinic Acid.}}{HO_2C.CH_2.CH_2COOH.}$$

By the energetic action of chlorine and bromine on pyromucic acid, halogen derivatives of formyl acrylic acid are produced—*mucochloric acid*, m.p. 125°, and *mucobromic acid*, m.p. 122°.

Similarly to the γ-Keto-acids (p. 421), these acids can be looked on as being hydroxylactones, with which they are *desmotropic* (M. **25**, 492):



Formyl Acrylic Acid.



Mucobromic Acid.

The *esters* of mucochloric and mucobromic acids, which, contrary to the acid, do *not* yield *oximes*, appear to be derived from the lactone formula; there are, however, also esters which have been obtained from the normal aldehyde-acid.

NITROGEN DERIVATIVES OF THE ALDEHYDE-ACIDS

Dinitro-acetic Ester, $(NO_2)_2CHCO_2C_2H_5$, is prepared from malonic ester and fuming nitric acid. It is a colourless liquid, which cannot be distilled without decomposition. It reacts strongly acid.

Diaminoacetic Acid, $(NH_2)_2CHCOOH$, is as yet unknown. A derivative *Tetramethyl Diaminoacetic Methyl Ester*, $[(CH_3)_2N]_2CHCOOCH_3$, $b.p._{12}$ 57°, is obtained from diiodoacetic ester and dimethylamine. Dibromacetic ester, by the same reaction, yields *Hydroxy-dimethyl Aminoacetic Dimethyl Amide*, $(CH_3)_2NCH(OH)CON(CH_3)_2$, $b.p._{12}$ 80° (B. **35**, 1378)

Diazoacetic Acid, $N_2CH.CO_2H$, is also a derivative of glyoxylic acid. As it contains two doubly-linked nitrogen atoms, it may be compared with the *aromatic diazo-bodies* (see Diazobenzene). However, in the latter the extra affinities of the diazo-group —N=N— or =N≡N are combined to two atoms, whilst in diazoacetic acid they are joined to a single carbon atom,  $\overset{N}{\underset{N}{\|}}\rangle CH.CO_2H$. Separated by acids from its salts, it undergoes an immediate decomposition, but it is fairly stable in its esters and its amides.

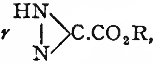
(1) The esters of the diazo-acids result when potassium nitrite acts on the hydrochlorides of the amino-fatty acid esters (p. 384) (*Curtius*, 1883, B. **29**, 759):

$$\underset{\text{Glycocoll Ester Hydrochloride.}}{HCl.(H_2N)CH_2CO_2C_2H_5}+KNO_2=\underset{\text{Diazoacetic Ester.}}{N_2{:}CHCO_2C_2H_5}+KCl+2H_2O.$$

The di- and poly-peptide ester hydrochlorides, which contain the NH_2CH_2CO-group, behave with alkali nitrites in the same way as glycocoll ester hydrochloride: highly crystalline diazo-esters are formed, such as *Diazoacetyl Glycine Ester*, $N_2CH.CONHCO_2C_2H_5$, m.p. 187°, as yellow crystals: *Diazoacetyl Glycyl Glycine Ester*, $NH_2CHCO.NHCH_2CONHCH_2CO_2C_2H_5$, etc. The homologous α-amino-acids, such as alanine leucine, also yield diazo-esters, if somewhat less readily; but β- and γ-amino-esters give hydroxy-esters instead of diazo-compounds (B. **37**, 1263).

(2) The sodium salts of the diazo-acids are prepared by reduction of the iso-nitramine fatty acids (p. 396) by means of sodium amalgam (B. **29**, 667):

$$HO_2N_2CH_2CO_2Na+2H=2H_2O+N_2{:}CH.CO_2Na.$$

The diazoacetic esters are very volatile, yellow-coloured liquids, with a peculiar odour. They distil undecomposed with steam, or under reduced pressure. They are slightly soluble in water, but mix readily with alcohol and ether. Like acetoacetic ester, they are feeble acids in which the hydrogen of their CHN_2-group can be replaced by alkali metals by means of anhydrous alcoholates. Isomerization occurs, and there are formed salts of *isodiazoacetic ester* , which can be obtained as an unstable oil by careful precipitation. It can be differentiated from the true diazoacetic ester by the fact that warm acids do not liberate N_2 from it (p. 404), but decompose it into hydrazine and oxalic acid (p. 405) (B. **34**, 2506). Aqueous alkalis gradually hydrolyze and dissolve true diazoacetic ester, forming salts, $CHOC_2.CO_2Me$, which are decomposed by acids, evolving nitrogen.

Sodium Diazoacetate, yellow in colour, dissolves with extreme ease in water. The reaction of its solution is alkaline (B. **34**, 2521).

Ethyl Diazoacetate, $N_2CHCO_2C_2H_5$, m.p. −24°, b.p. 143°, $D_{22}=1{\cdot}073$, explodes with violence when brought into contact with concentrated sulphuric acid. A blow does not have this effect. At temperatures near its boiling point it decomposes into nitrogen and fumaric ester. Its *mercury salt*, $Hg(CN_2.CO_2.C_2H_5)_2$, m.p. 104°, with formation of froth, results when yellow mercuric oxide acts on diazoacetic ester while being well cooled. It separates from ether in transparent, sulphur-yellow, rhombic crystals. Concentrated ammonia converts it, like all other esters, into an amide, *diazoacetamide*, $N_2CHCONH_2$, m.p. 114° with decomposition. When diazoacetic ester is reduced it breaks down into ammonia and glycocoll. *Pseudo-* and *bis-diazoacetamide* (see below). *Diazoacetonitrile*, $N_2CH.COCN$, m.p.$_{14}$ 46°, is prepared from amino-acetonitrile hydrochloride (p. 386) and sodium nitrite (B. **31**, 2489). It is an orange-yellow, very mobile liquid, possessing a pleasant odour resembling acetonitrile, but which irritates the mucous membrane.

The diazo-fatty acid compounds are all very reactive, by reason of the easy replacement of nitrogen by *two* monovalent atoms or groups; or else by the ability to form nitrogen ring-systems (Vol. II.) by means of addition or reaction compounds without simultaneous loss of nitrogen.

(1) The diazo-esters are converted, by boiling water or dilute acids, into esters of the *hydroxy-fatty acids* (glycol acids, p. 358):

$$N_2CHCO_2C_2H_5+H_2O=\underset{\text{Ester of Glycollic Acid.}}{CH_2(OH)CO_2C_2H_5}+N_2$$

This reaction can serve for the quantitative estimation of the nitrogen in diazo-derivatives. (2) Alkyl glycollic esters are produced on boiling with alcohols:

$$N_2CHCO_2C_2H_5+C_2H_5OH=\underset{\text{Ethyl Glycollic Ethyl Ester.}}{CH_2(OC_2H_5)CO_2C_2H_5}+N_2;$$

a small quantity of aldehyde is produced at the same time.

(3) Acid derivatives of the glycollic esters are obtained on heating the diazo-compounds with organic acids:

$$N_2CHCO_2C_2H_5+\underset{\text{Acetic Acid.}}{C_2H_3OOH}=\underset{\text{Aceto-glycollic Ester.}}{CH_2(OC_2H_3O)CO_2H_5}+N_2.$$

(4) The halogen acids act, even in the cold, on the diazo-compounds. The products are *haloid fatty acids:*

$$N_2CHCO_2C_2H_5+HCl=CH_2ClCO_2C_2H_5+N_2.$$

(5) The halogens produce esters of dihaloid fatty acids:

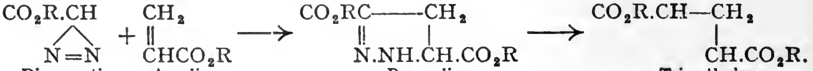
$$NCH_2CO_2C_2H_5+I_2=\underset{\text{Di-iodo-acetic Ester.}}{CHI_2CO_2C_2H_5}+N_2.$$

Diazoacetamide is changed, in a similar manner, to di-iodo-acetamide, $CHI_2.CO.NH_2$. By titration with iodine it is possible to employ this reaction for the quantitative estimation of diazo-fatty compounds (B. **18**, 1285).

(6) The *esters* of *anilino-fatty acids*, $C_6H_5NH.CH_2CO_2R$, result from the union of the anilines with diazo-esters.

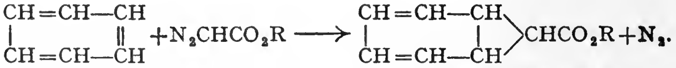
(7) The esters of the diazo-fatty acids unite with aldehydes to form *esters* of the *β-ketonic acids, e.g.* benzoyl acetic ester, $C_6H_5CO.CH_2CO_2C_2H_5$, trichloraceto-acetic ester, $CCl_3COCH_2CO_2R$ (comp. p. 218) (B. **18**, 2379; **40**, 3000).

(8) Diazoacetic ester forms well-crystallizable addition products with unsaturated acid esters, such as acrylic, cinnamic, fumaric esters. Pyrazoline-carboxylic esters (Vol. II.) are thus formed, which, on heating lose nitrogen and are converted into *trimethylene dicarboxylic ester, e.g.*—



Diazoacetic Acid. Acrylic Acid. Pyrazoline Dicarboxylic Ester. Trimethylene Dicarboxylic Ester.

(9) Diazoacetic ester also unites with benzene and its homologens, on being heated with them, loses nitrogen and forms dicyclic bodies, such as benzotrimethylene or norcaradiene carboxylic esters (Vol. II.) (B. **29**, 108; **32**, 701; A. **358**, 1):

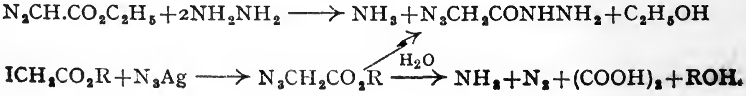


Benzene. Pseudophenylacetic Ester

(10) Diazoacetamide is converted into *triazolone* when heated with barium hydroxide solution (Vol. II.):

Diazoacetyl glycinamide (see above) similarly yields triazolone acetamide (B. **39**, 4140).

(11) Hydrazine and diazoacetic ester or dizaoacetamide form the hydrazide of *azidoacetic acid*, $N_3CH_2CO_2H$, of which the *ethyl ester*, b.p.$_{21}$ 75°, is prepared from iodoacetic ester and silver azide or chloracetic ester and sodium azide. It is a colourless oil. Boiling alkalis decompose the acid into ammonia, nitrogen and oxalic acid (B. **41**, 344; C. 1908, I. 938):

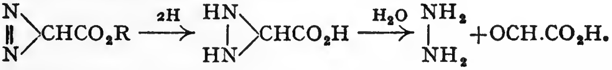


$$N_2CH.CO_2C_2H_5+2NH_2NH_2\longrightarrow NH_3+N_3CH_2CONHNH_2+C_2H_5OH$$

$$ICH_2CO_2R+N_3Ag\longrightarrow N_3CH_2CO_2R\xrightarrow{H_2O}NH_3+N_2+(COOH)_2+ROH.$$

(12) Diazoacetic ester has been made to yield *diamide* or *hydrazine*, NH_2NH_2 by different sets of reactions (*Curtius*), and from these *hydrazoic acid,* N_3H, has been obtained (see Inorg. Chem.):

(*a*) Moderate reduction of diazoacetic esters leads to the formation of salts of *hydraziacetic acid*—in which form only it is stable—decomposable by acids into *glyoxylic acid* and *hydrazine* (B. **27,** 295):



Energetic reduction decomposes diazoacetic ester into ammonia and glycocoll.

Diazo-acids can be made to yield hydrazine fatty acids by reduction (B. **29,** 670).

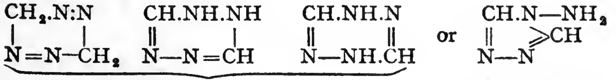
(*b*) Diazoacetic ester and *concentrated* sodium hydroxide solution form the salt of *bisdiazoacetic* acid, which is a polymer of the *iso*-form of the acid (p. 403 isodiazoacetic acid). The basis for the assigned constitution is that, like isodiazoacetic acid, it does not evolve nitrogen when warmed with acids, but decomposes into *hydrazine* and *oxalic* acid :

$$\underset{\text{Bis-diazo-acetic Acid.}}{H_2N_4C_2(COOH)_2}+4H_2O=\underset{\text{Hydrazine.}}{2H_4N_2}+\underset{\text{Oxalic Acid.}}{2HOCO.COOH.}$$

(*c*) Ammonia and diazoacetic acid yield, besides diazoacetamide (p. 404), also *bis-diazoacetamide* and *pseudo-diazoacetamide*; the latter decomposes when boiled with water into nitrogen and the *azine* of *glyoxylic amide,* which can be further broken down into *hydrazine* and glyoxylic amide :

$$\underset{\text{Pseudo-diazo Acetamide.}}{N_4(CHCONH_2)_2} \longrightarrow \underset{\text{Glyoxylic Amide Azine.}}{N_2+N_2(:CHCONH_2)_2} \longrightarrow \underset{\text{Hydrazine.}}{N_2H_4}+\underset{\text{Glyoxylic Amide.}}{2OCH.CONH_2.}$$

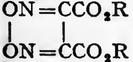
Oxidation converts pseudo-diazoacetamide into the red *tetrazine dicarboxylic amide.* The bis-diazoacetic acid and pseudo-diazoacetic acid and reaction products of these acids are derived from dihydrotetrazine or aminotriazoles (Vol. II.) (B. **39,** 3776):



Dihydrotetrazine. Aminotriazole.

Oxime and Hydrazone derivatives of the Aldocarboxylic Acids.

Oximidoacetic Acid, Isonitrosoacetic Acid, Glyoxylic Oxime, HON : CH.COOH, m.p. 143° with decomposition, is prepared from glyoxylic acid and hydroxylamine; from dichlor- or dibromacetic acid, hydroxylamine and potassium hydroxide solution; and from the hydrolysis of its ester. It forms colourless needles. *Isonitrosoacetic Ethyl Ester,* m.p. 35°, b.p.$_{12}$ 111°, consists of deliquescent crystals; *methyl ester,* m.p. 55°, b.p.$_{15}$ 100°; *isobutyl ester,* b.p.$_{10}$ 118°, can be prepared from acetoacetic ester by decomposition with nitroxyl sulphuric acid. Treatment with acetic anhydride converts isonitrosoacetic ester into *cyanoformic ester,* $NC.CO_2R$; N_2O_4, produces *isonitrosonitroacetic ester,* $HONC(NO_2)$-CO_2R, and an oily substance, probably a *peroxide* of *dioximidosuccinic ester :*



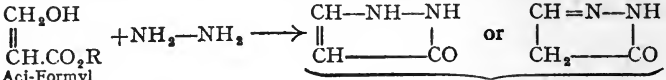
$$\begin{array}{l} ON=CCO_2R \\ | \quad\;\; | \\ ON=CCO_2R \end{array}$$

(comp. B. **28,** 1216; **37,** 1530; C. 1904, II. 195; 1907, I. 401).

β-Oximidopropionic Acid, Formyl Acetic Acid Oxime, $HON : CHCH_2COOH$, m.p. 117° with decomposition, is prepared from coumalic acid and hydroxylamine (comp. p. 401) (A. **264,** 286; B. **25,** 1904).

Glyoxylic Acid Phenylhydrazone, $C_6H_5NHN : CHCO_2H$, m.p. 137° with decomposition, is decomposed by nitrous acid into CO_2 and *phenyl azoformaldoxime,* $C_6H_5N : NCH : NOH$ (J. pr. Ch. [2] **71,** 366); *ethyl ester,* m.p. 131°, can be distilled under reduced pressure (C. 1907, I. 401).

Hydrazones of β-Aldocarboxylic Acids, such as of formyl acetic acids, and their esters very easily part, intramolecularly, with water or alcohol, forming lactam-like bodies, known as *pyrazolones* (Vol. II.). In order to indicate the lactam character of such substances, when the lactam-nitrogen is joined to a second nitrogen atom in the ring, they have been named *lactazams* :



Aci-Formyl Acetic Acid.

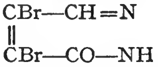
Pyrazolone.

β-Ketocarboxylic acids (p. 416) also easily form γ-lactazams (pyrazolones).

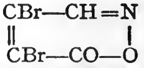
Hydrazones of the γ- and δ-Aldocarboxylic Acids.

β-Formyl Propionic Acid Ester Phenylhydrazone is a non-crystallizable oil; *phenylhydrazide*, $C_6H_5NHN:CHCH_2CH_2CONHNHC_6H_5$, m.p. 182°, is prepared from aconic acid (*q.v.*) and excess of phenylhydrazine. When warmed with sulphuric acid it yields indole β-acetic acid (A. **339**, 373). Similarly, *Formyl Butyric Acid Phenylhydrazone*, $C_6H_5NHN:CHCH_2CH_2CH_2COOH$, yields indole β-propionic acid, which is also formed from tryptophane by putrefaction (B. **38**, 2884).

Mucobromic acid (p. 402) and hydrazines form *hydrazone anhydrides* or *δ-lactazams* (Pyridazones, Vol. II.); with hydroxylamine it gives an *oxime anhydride* (*lactazone* or *orthoxazone*, Vol. II.) (B. **32**, 534):



Dibromopyridazone, m.p. 224°.



Dibromo-orthoxazone m.p. 125°.

9. KETONIC CARBOXYLIC ACIDS

These contain both the groups CO and CO_2H; they, therefore, show acid and ketone characters with all the specific properties peculiar to both. In conformity with the scheme of nomenclature employed for the mono-substituted fatty acids and the various diketones (pp. 284, 348), we distinguish the groups α-, β-, γ-, δ-, etc., among the *ketocarboxylic acids :*

The α-, γ-, and δ-, etc., acids are fairly stable in a free condition, whilst the β-acids can exist only in the form of esters.

Nomenclature.—The names of the ketonic acids are usually derived from the fatty acids, inasmuch as the acid radicals are introduced into these ; *e.g.*—

$CH_3CO.CO_2H$	$CH_3CO.CH_2CO_2H$	$CH_3CO.\overset{\beta}{C}H_2\overset{\alpha}{C}H_2CO_2H$
Acetyl Formic Acid.	Acetyl- or Aceto-acetic Acid.	β-Acetyl Propionic Acid.

or these acids may be viewed as *keto*-substitution products of the fatty acids or oxofatty acids (p. 218) :

$CH_3.CO.CO_2H$	$CH_3.CO.CH_2CO_2H$	$CH_3.CO.CH_2CH_2CO_2H$
α-Ketopropionic Acid (α-Oxopropionic Acid).	β-Ketobutyric Acid (β-Oxobutyric Acid).	γ-Ketovaleric Acid (γ-Oxovaleric Acid).

The "Geneva names" are formed by the addition of the word "acid" to the names of the ketones, as the ketonic acids may be considered as being the oxidation products of the latter :

CH_3COCO_2H	$CH_3CO.CH_2CO_2H$	$CH_3COCH_2CH_2CO_2H$.
[Propanone Acid].	2-Butanone Acid].	[3-Pentanone Acid].

Formation.—The more stable α-, γ-, and δ-ketonic acids can be prepared by the oxidation of the secondary alcohol acids corresponding with them. Other methods will be given under the individual classes of these acids.

Reactions.—The ketone nature of these acids exhibits itself in numerous reactions, *e.g.* nascent hydrogen converts all the ketonic acids into the corresponding alcohol acids. They unite with alkali hydrogen sulphites, with hydroxylamine, and with phenylhydrazine.

A. SATURATED KETONE CARBOXYLIC ACIDS

I. *α*-Ketonic Acids.—R.CO.CO_2H.

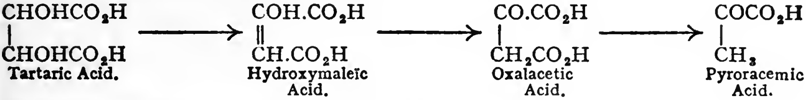
In this class the ketone group CO is in direct union with the acid-forming carboxyl group, CO_2H. We can look upon them as being compounds of acid radicals with carboxyl, or as derivatives of formic acid, HCO.OH, in which the hydrogen linked to carbon is replaced by an acid radical. This view indicates, too, the general synthetic method of formation of these acids from (1) the cyanides of acid radicals (p. 409), which, by the action of concentrated hydrochloric acid, are changed to the corresponding ketonic acids:

$$CH_3.CO.CN + 2H_2O + HCl = CH_3.CO.CO_2H + NH_4Cl.$$

(2) A second general method of formation of *α*-ketonic acids and their esters consists in converting *α*-alkyl acetoacetic esters into the *α*-oximido-fatty acids (p. 410) and decomposing these with nitrosyl sulphuric acid (C. 1904, II. 1706):

$$HON{:}CRCOOC_2H_5 \xrightarrow{HNO_2} O{:}CRCOOC_2H_5 + N_2O + H_2O.$$

Pyroracemic Acid, *Pyruvic Acid, Acetyl Formic Acid*, [Propanone Acid], $CH_3.CO.CO_2H$, m.p. +3°, b.p.$_{760}$ 165–170° with decomposition, b.p.$_{12}$ 61°, was first obtained in the distillation of tartaric acid, racemic acid (*Berzelius*, 1835) and glyceric acid. (1) The acid is made by the distillation of tartaric acid alone (A. **172**, 142) or with potassium hydrogen sulphate (B. **14**, 321). We may assume that in this decomposition the first product is hydroxymaleïc acid, which is converted into oxalacetic acid, which then gives up CO_2 to form pyroracemic acid:



$$\begin{matrix} CHOHCO_2H \\ | \\ CHOHCO_2H \\ \text{Tartaric Acid.} \end{matrix} \longrightarrow \begin{matrix} COH.CO_2H \\ \| \\ CH.CO_2H \\ \text{Hydroxymaleïc Acid.} \end{matrix} \longrightarrow \begin{matrix} CO.CO_2H \\ | \\ CH_2CO_2H \\ \text{Oxalacetic Acid.} \end{matrix} \longrightarrow \begin{matrix} COCO_2H \\ | \\ CH_3 \\ \text{Pyroracemic Acid.} \end{matrix}$$

It is synthetically prepared from (2) *α*-dichloropropionic acid (p. 289), when heated with water; (3) in the oxidation of *α*-hydroxypropionic acid or ordinary lactic acid with potassium permanganate; (4) by the decomposition of oxalacetic ester; (5) from acetyl cyanide by the action of hydrochloric acid (p. 409); (6) by the oxidation of citraconic and mesaconic acid by $KMnO_4$.

Pyroracemic acid is a liquid, soluble in alcohol, water and ether, and has an odour quite similar to that of acetic acid. On boiling at atmospheric pressure it decomposes partially into CO_2 and pyrotartaric acid (*q.v.*). This change is more readily effected if the acid be heated to 100° with hydrochloric acid.

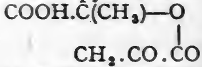
Reactions.—The acid reduces ammoniacal silver solutions with the production of a silver mirror, the decomposition products being CO_2 and acetic acid. It is quantitatively decomposed into these substances by hydrogen peroxide (C. 1904, II. 194). When heated with dilute sulphuric acid to 150° it splits up into CO_2 and aldehyde, $CH_3.COH$. This ready separation of aldehyde accounts for the ease with which pyroracemic acid enters into various condensations, *e.g.* the formation of crotonic acid by the action of acetic anhydride (p. 291) (B. **18**, 987, and **19**, 1089), and the condensations with dimethyl aniline and phenols in the presence of $ZnCl_2$. The acid condenses with the benzene hydrocarbons, in the presence of sulphuric acid, without decomposition (B. **14**, 1595; **16**, 2072). (See also, Acetone Pyroracemic Acid.)

Pyruvic acid forms crystalline compounds with the alkali hydrogen sulphites, in which it resembles the ketones. Nascent hydrogen (Zn and HCl, or HI) changes it to ordinary α-lactic acid, $CH_3CH(OH)CO_2H$, and dimethyl racemic acid (comp. Glyoxylic Acid, p. 400). H_2S passed through pyroracemic acid produces *thiodilactic acid*, $S[C(CH_3)(OH)COOH]_2$, m.p. 94°, which is easily decomposed into its components (C. 1903, I. 16). Mercaptans, *e.g.* phenylmercaptan, combine with pyroracemic acid to form $CH_3C(OH)(SC_6H_5)CO_2H$ (B. **28**, 263). Pyroracemic ester, mercaptan and hydrochloric acid react together to form the *mercaptol* $CH_3.C(SC_2H_5)_2CO_2C_2H_5$, which on oxidation passes into $CH_3C(SO_2C_2H_5)_2CO_2C_2H_5$, m.p. 61° (B. **32**, 2804).

For the behaviour of pyroracemic acid with NH_3, NH_2OH, $C_6H_5NHNH_2$, see "Nitrogen derivatives of the α-ketonic acids." It combines with HNC to form the half-nitrile of α-hydroxyiso-succinic acid.

The change of pyroracemic acid on boiling with barium hydroxide solution into *uvitic acid*, $C_6H_3[1,3,5](CH_3)(CO_2H)_2$ (Vol. II.) and *uvic acid* or *pyrotritaric acid* (Vol. II.), is noteworthy. The first step is the separation of oxalic acid with the formation of methyl dihydrotrimesic acid; then, CO_2 is given off and dihydrouvitic acid results; finally, oxidation produces uvitic acid (A. **305**, 125). These intermediate compounds can be avoided by condensing pyroracemic acid with acetaldehyde, a reaction which is of general application. For the condensation of pyroracemic acid with formaldehyde, see tetramethylene dioxalic acid (Vol. II.).

On standing, a slow aldol-like condensation takes place, which can be accelerated by the presence of hydrochloric acid, whereby two molecules of pyroracemic acid unite to form α-ketovalerolactone γ-carboxylic acid,



$$\begin{array}{r} COOH.C(CH_3)\text{—}O \\ | \\ CH_2.CO.CO \end{array}$$

(*q.v.*). Heated with hydrochloric acid this substance gives up CO_2, and pyrotartaric acid is formed (see also C. 1904, II. 1453). The salts of pyroracemic acid are caused to undergo polymerization by the action of alkalis to salts of *para-pyroracemic acid* and *meta-pyroracemic acid* (A. **317**, 1; **319**, 121; C. 1901, II. 1262; 1903, I. 16).

Pyroracemic Ethyl Ester, m.p. 146°; *acetal*, $CH_3C(OC_2H_5)_2.CO_2C_2H_5$, b.p. 190° (see also α-ethoxy acrylic ester, p. 397).

Halogen Substitution Products of Pyroracemic Acid.—*Trichloropyroracemic Acid, Isotrichloroglyceric Acid*, $CCl_3.CO.CO_2H+H_2O=CCl_3.C(OH)_2COOH$, m.p. 102°, is produced (1) when $KClO_3$ and HCl act on gallic acid and salicylic acid; (2) by the action of chlorine water on chlorofumaric acid (B. **26**, 656); (3) from trichloracetyl cyanide.

Substitution products result by heating the acid with bromine and water to 100°. *Dibromopyruvic Acid*, $CBr_2HC(OH)_2CO_2H+H_2O$, m.p. 89°, anhydrous. *Tribomopyruvic Acid*, $CBr_3C(OH)_2.CO_2H+H_2O$, m.p. 90°, anhydrous. Heated with water or ammonia, it breaks up into bromoform, $CHBr_3$, and oxalic acid.

Homologues of Pyroracemic Acid, *Homopyroracemic Acids.*

Propionyl Formic Acid, $CH_3CH_2CO.COOH$, b.p.$_{25}$ 74–78°, is also obtained by the transformation of vinyl glycollic acid (p. 397); *ethyl ester*, b.p. 162° (C. 1904, II. 1706). *Butyryl Formic Acid*, $CH_3CH_2CH_2CO.CO_2H$, b.p.$_{83}$ 115°; *ethyl ester*, b.p.$_{10}$ 72–77°, is produced from α-oximidovaleric ester (mode of formation No. 2, p. 407). *Dimethyl Pyroracemic Acid*, $(CH_3)_2CHCO.COOH$, m.p. 31°, b.p.$_{10}$ 66°, is produced by the cleaving action of hydrochloric acid on dimethyl-2-amino-acrylic acid (p. 399) (C. 1902, I. 251). *Trimethyl Pyroracemic Acid*, $(CH_3)_3C.CO.COOH$, m.p. 90°, b.p. 185°, results when pinacoline is oxidized with $KMnO_4$ (B. **23**, R. 21; C. 1898, I. 202). *Isobutyl Pyroracemic Acid*, $(CH_3)_2CHCH_2.CH_2CO.COOH$, m.p. 22°, is obtained from isobutyl citraconic acid and isobutyl mesaconic acid (A. **305**, 60); *ethyl ester*, b.p.$_{11}$ 74°, is prepared from α-oximidoisocaproic ester (C. 1904, II. 1737; 1906, II. 1824).

NITROGEN DERIVATIVES OF THE α-KETONIC ACIDS

(1) **Carboxyl Cyanides, α-Ketone Nitriles** result on heating acid chlorides or bromides with silver cyanide:

$$C_2H_3O.Cl + AgNC = C_2H_3O.CN + AgCl;$$

and when the aldoximes of the α-aldehyde ketones are treated with dehydrating agents, such as acetic anhydride (p. 353) (B. **20**, 2196):

$$CH_3.CO.CH{:}NOH = CH_3.CO.CN + H_2O.$$

The acid cyanides are not very stable, and, unlike the alkyl cyanides, are converted by water or alkalis into their corresponding acids and hydrogen cyanide,

$$CH_3CO.CN + H_2O = CH_3CO.OH + HNC.$$

With concentrated hydrochloric acid, on the contrary, they undergo a transposition similar to that of the alkyl cyanides (p. 280), in which water is absorbed, and the amides of the α-ketonic acids are intermediate products (*Claisen*):

$$CH_3COCN \xrightarrow{H_2O} CH_3COCONH_2 \xrightarrow[HCl]{H_2O} CH_3COCOOH + NH_4Cl.$$

Acetyl Cyanide, $CH_3CO.CN$, b.p. 93°. When preserved for some time, or by the action of KOH or sodium, it is transformed into *Diacetyl Cyanide,* $C_6H_6O_2N_2$, m.p. 69°, b.p. 208°, which can also be prepared from acetic anhydride, potassium cyanide and hydrochloric acid in ether at 0°. Hydrolysis converts it into methyl tartronic acid, probably according to the following scheme (M. **15**, 773):—

Diacetyl Cyanide. Methyl Tartronic Acid.

Pyruvic Nitrile, *Propionyl Cyanide,* CH_3CH_2COCN, b.p. 108–110°. *Dipropionyl Cyanide,* $(C_3H_5OCN)_2$, m.p. 59°, and b.p. 200–210°, behaves like diacetyl cyanide (B. **26**, R. 372). *Butyryl Cyanide,* C_3H_7COCN, b.p. 133–137°, and *isobutyryl cyanide,* C_3H_7COCN, b.p. 118–120°, polymerize readily to dicyanides, which pass into alkyl tartronic acids on treatment with hydrochloric acid.

Pyroracemic Amide, $CH_3CO.CONH_2$, m.p. 124°. *Propionyl Formamide,* $C_2H_5CO.CONH_2$, m.p. 116°, is produced from α-ketone nitriles and concentrated hydrochloric acid (B. **13**, 2121).

Pyruvyl Ethyl Imidochloride, $CH_3COCCl : NC_2H_5$, is a yellowish oil produced by the union of chloracetyl with ethylisocyanide (A. **289**, 298).

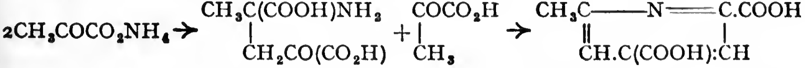
Pyruvyl Hydroximic Chloride, Chlorisonitrosoacetone, $CH_3COC(NOH)Cl$, m.p. 105°, is formed:

By the action of nitric acid on chloracetone;

By the action of chlorine on isonitrosoacetone;

When hydrochloric acid acts on *Pyruvyl Nitrolic Acid, Acetyl Methyl Nitrolic Acid,* $CH_3CO.C(=NOH)ONO$ or $CH_3.CO.C(=NOH)NO_2$—the product resulting from the action of nitric acid on acetone (A. **309**, 241). The *oxime,* $CH_3.C{:}NOH.C({:}NOH)O.NO$, m.p. 97° with decomposition.

(2) *Behaviour of Ammonia and Aniline with Pyroracemic Acid.*—The ammonium salt, like the other alkali salts, undergoes condensation in neutral or alkaline solution. At first an amino-ketone dicarboxylic acid is formed, which loses formic acid and passes into *uvitonic acid,* a picoline dicarboxylic acid (C. 1904, II. 192):



$$2CH_3COCO_2NH_4 \rightarrow \begin{array}{c} CH_3C(COOH)NH_2 \\ | \\ CH_2CO(CO_2H) \end{array} + \begin{array}{c} COCO_2H \\ | \\ CH_3 \end{array} \rightarrow \begin{array}{l} CH_3C\text{——}N\text{══}C.COOH \\ \| \qquad\qquad\qquad\quad | \\ CH.C(COOH){:}CH \end{array}$$

Aniline and pyroracemic acid produce *anil-pyruvinic acid,* $C_6H_5N : C(CH_3)$-COOH, m.p. 126°, with decomposition, which undergoes a similar condensation with a further molecule of pyroracemic acid to form α-methyl cinchonic acid, forming *anil-uvitonic acid* (Vol. II.).

In acid solution one molecule of NH_3 and two of pyroracemic acid unite to form *iminodilactic acid* (comp. Thiodilactic Acid, p. 408), with the probable formation of intermediate compounds. On losing CO_2 it forms acetyl alanine (p. 388) (C. 1904, II. 193):

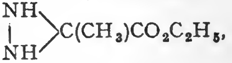
$$CH_3C(COOH)(OH)NHC(OH)(CH_3)COOH \xrightarrow[-H_2O]{-CO_2} CH_3CONH.CH(CH_3)CO_2H.$$

(3) *α-Oximido-fatty Acids* or *oximes* of the *α-ketone acids* are formed (*a*) by the action of NH_2OH on *a*-ketone acids; (*b*) by the interaction of mono-alkyl acetoacetic acid and nitrous acid, alkyl nitrites, nitrosyl sulphuric acid or nitrosyl chloride (B. **11**, 693; **15**, 1527; C. 1904, II. 1457, 1706):

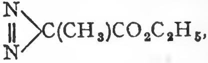
$$CH_3COCH(CH_3)CO_2R+HO_2SONO \longrightarrow CH_3CO_2SO_3H+HON:C(CH_3)CO_2R$$

Further action of nitrous acid converts the α-oximido-esters into α-ketone esters (p. 407). Acetic anhydride causes the splitting off of water and CO_2 with formation of acid nitriles.

α-Oximidopropionic Acid, Isonitrosopropionic Acid, $CH_3C{=}N(OH).CO_2H$, decomposes at 177°; *methyl ester*, m.p. 69°, b.p.$_{14}$ 123°; *ethyl ester*, $CH_3C{=}N(OH)CO_2C_2H_5$, m.p. 94°, b.p. 238° (B. **27**, R. 470); *amide*, $CH_3.C:N(OH)\text{-}CONH_2$, m.p. 174° (B. **28**, R. 766; C. 1904, II. 1457). *α-Oximidobutyric Acid*, $CH_3.CH_2C{=}(NOH)CO_2H$. α-Oximidovalerianic acid, and a number of other homologues and their esters have also been prepared. *α-Oximido-Dibromopyroracemic Acid* has been obtained in two modifications (B. **25**, 904).



(4) *Hydrazipropionic Ethyl Ester*, $\begin{matrix}NH\\|\\NH\end{matrix}\!\!>C(CH_3)CO_2C_2H_5$, m.p. 116° (J. pr. Ch. [2] **44**, 554), results from pyroracemic acid and hydrazine. Mercuric oxide converts its methyl ester into *a*-diazopropionic methyl ester.



(5) *α-Diazopropionic Ester*, $\begin{matrix}N\\\|\\N\end{matrix}\!\!>C(CH_3)CO_2C_2H_5$, b.p.$_{11}$ 65–68°, is obtained from the hydrochloride of alanine ethyl ester by the action of KNO_2. It is a yellow oil, which is partially decomposed, by distillation at ordinary pressure, into dimethyl fumaric ethyl ester. *α-Diazobutyric Ester*, b.p.$_{11}$ 63–65°, and *α-Diazoisocaproic Ester*, b.p.$_{12}$ 70–73°, both resemble diazoacetic ester (p. 403) in their behaviour, but are more easily decomposed, and are therefore more difficult to obtain pure (B. **37**, 1261).

(6) *Phenylhydrazone Pyroracemic Acid*, $CH_3C({=}NNHC_6H_5)CO_2H$, m.p. about 192° with decomposition, is not only formed by the action of phenylhydrazine on pyroracemic acid (B. **21**, 984), but also in the saponification of the reaction-product from diazobenzene chloride and methyl acetoacetic ester (B. **20**, 2942, 3398; **21**, 15; A. **278**, 285; C. 1901, II. 212).

Pyroracemic ethyl ester yields two isomers with phenylhydrazine, which are separable by chloroform: *phenylhydrazones*, m.p. 32° and 119° (C. 1900, II. 1150).

(7) *Semicarbazones* of the α-Ketonic Acids, $NH_2CO.NHN:CRCO_2H$, and their esters, see C. 1904, II. 1706, etc.

II. β-Ketonic Acids.

In the β-ketonic acids the ketone oxygen atom is attached to the second carbon atom, counting from the carboxyl group forward. These compounds are very unstable either in the free state or as salts. Heat decomposes them into carbon dioxide and ketones. The CO and CO_2H groups are attached to the same carbon atom, and, in this respect, direct attention to malonic acid and its mono- and di- substitution products (see later), in which two carboxylic groups are attached to the same carbon atom; they also give off CO_2 when heated. Their esters, on the other hand, are very stable, can be distilled without decomposition, and serve for various and innumerable syntheses.

Acetoacetic Acid, *Acetyl Acetic Acid, Acetone Monocarboxylic Acid, β-Ketobutyric Acid* [3-Butanone Acid], $CH_3.CO.CH_2.CO_2H$. To obtain the acid, the esters are hydrolyzed *in the cold* by dilute potassium hydroxide solution (the rate of hydrolysis is independent of the concentration: B. **32,** 3390; **33,** 1140); the acid is liberated with sulphuric acid, and the solution shaken with ether (B. **15,** 1781; **16,** 830). Concentrated over sulphuric acid, acetoacetic acid is a thick liquid, strongly acid, and miscible with water. When heated, it yields carbon dioxide and acetone:

$$CH_3CO.CH_2CO_2H = CH_3CO.CH_3 + CO_2.$$

Nitrous acid converts it at once into CO_2 and isonitroso-acetone (p. 354). Its salts are not very stable; it is difficult to obtain them pure, since they undergo changes similar to those of the acid. Ferric chloride imparts to them, and also to the esters, a violet-red coloration. Occasionally the sodium or calcium salt is found in urine (B. **16,** 2134; C. 1900, II. 345).

The *homologous β-Ketone acids* can also be prepared by the hydrolysis of their esters with hot concentrated sulphuric acid: the resulting liquid may contain the sulphates of the *aci-* and *enol* forms: $RC(OSO_3H)CHCO_2H$. The free acids, like acetoacetic acid itself, easily decompose into CO_2 and ketones (C. 1904, II. 1707).

The stable acetoacetic esters, $CH_3CO.CH_2CO_2R$, are produced by the action of metallic sodium on acetic esters. In this reaction the sodium compounds constitute the first product:

$$\underset{\text{Acetic Ester.}}{2CH_3COOC_2H_5} + Na_2 \longrightarrow \underset{\text{Sodium Acetoacetic Ester.}}{CH_3CONaCHCOOC_2H_5} + C_2H_5ONa + H_2.$$

The free esters result upon treating their sodium compounds with acids, *e.g.* acetic acid,

$$CH_3CONaCHCO_2C_2H_5 + CH_3CO_2H \longrightarrow CH_3COCH_2COOC_2H_5 + CH_3CO_2Na$$

and are obtained pure by distillation.

The acetoacetic esters are liquids, which dissolve with difficulty in water, and possess an ethereal odour. They can be distilled without decomposition.

The esters of acetoacetic acid, contrary to expectation, possess an *acid-like* character. They dissolve in alkalis, forming salt-like compounds in which a hydrogen atom is replaced by metals.

Historical.—In 1863 *Geuther* investigated the action of sodium on acetic ester. Simultaneously and quite independently of *Geuther*, *Frankland* and *Duppa*, in concluding their studies upon the action of zinc and alkyl iodides on oxalic ether (p. 358), investigated the action of sodium and alkyl iodides on acetic ester. *J. Wislicenus* has contributed very materially to the explanation of the reactions here involved (1877), A. **186,** 161.

Constitution.—The β-ketone acids belong to the same class of substances which includes the β-ketone aldehydes, β-diketones (p. 348), and β-aldocarboxylic acids (p. 401), namely those which occur in desmotropic or pseudomeric form (comp. p. 38); *e.g.* acetoacetic ester:

$$\underset{\beta\text{-Ketobutyric Acid.}}{CH_3CO.CH_2COOH} \longleftrightarrow \underset{\beta\text{-Hydroxycrotonic Acid.}}{CH_3C(OH){:}CHCOOH}$$

$$\underset{\text{Acetoacetic Ester.}}{CH_3CO.CH_2COOC_2H_5} \longleftrightarrow \underset{\text{Aci-Acetoacetic Ester.}}{CH_3C(OH){:}CH.COOC_2H_5}$$

Evidence for the Ketonic character of free Acetoacetic Ester.

The esters of β-aldocarboxylic acids, such as formyl acetic ester, show their constitution to be of the aci-form, and that therefore they must be considered as being hydroxymethylene compounds; the free acetoacetic ester, however, is best expressed by the formula, $CH_3COCH_2COOC_2H_5$. This substance, with orthoformic ester, gives an acetal, β-diethoxybutyric ester—$CH_3C(OC_2H_5)_2$·$CH_2.COOC_2H_5$, thus behaving like the simple ketones (p. 225).

The physical properties of the ester, its refraction (B. **31**, 1964), molecular rotation and behaviour towards electric waves, all point to a ketonic constitution.

Sodium acetoacetic ester was formerly also considered to possess the same structure and received the formula $CH_3CO—CHNaCOOC_2H_5$, because its reaction with alkyl and acyl halides always yielded a C-derivative, $CH_3COCHR.COOC_2H_5$. The first example of a different course of reaction was found in the formation of an O-derivative, β-carboxethyl hydroxycrotonic ester, $CH_3C(OCO_2C_2H_5):CHCO_2C_2H_5$, from sodium acetoacetic ester and chlorocarbonic ester (*Michael*, J. pr. Ch. [2] **37**, 473; *Claisen*, B. **25**, 1760, A. **277**, 64). It has, however, already been pointed out (p. 40) that substances which occur in the forms (1) —$CO.CH_2.CO$—, and (2) —$C.CH:C(OH)$—, only form salts directly according to the second formula. This occurs by the action of alkalis on the first substance, and acetoacetic ester can be taken as an example of this:

$$CH_3COCH_2COOC_2H_5+NaOH=CH_3C(ONa):CH.COOC_2H_5+H_2O.$$

These views on the varying structure of acetoacetic ester are confirmed by investigations on the refraction of the two forms (*Brühl* and *Schroder*, B. **38**, 220, 1870).

In the majority of cases of reaction between sodium acetoacetic ester with alkyl and acyl halides, the invading group enters another position than of the metallic atom. For the explanation of such "abnormal" reactions see *Michael*, J. pr. Ch. [2] **37**, 473, etc. (also p. 413).

As the β-ketonic acids are so very unstable, their more stable esters are employed in their study. These can be made according to the following reactions:

Formation of Acetoacetic Ester and its Homologues.

(1) By the action of sodium or sodium alcoholate on acetic ester. These reagents act similarly on propionic ester, with the formation of α-propionyl propionic ester, $CH_3CH_2CO.CH(CH_3)CO_2C_2H_5$.

However, when sodium acts on normal butyric ester, isobutyric ester and isovaleric ester, it is not the analogous bodies which result, but hydroxy-alkyl derivatives of higher fatty acids (A. **249**, 54).

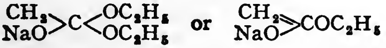
The reaction between sodium and acetic ester only takes place in the presence of a trace of alcohol, with which the sodium can combine to form the alcoholate (B. **3**, 305). It must be assumed, therefore, that the condensation is brought about by the action of sodium ethoxide, which causes the splitting off of alcohol:

$$2CH_3COOC_2H_5+NaOC_2H_5=CH_3C(ONa):CHCOOC_2H_5+2C_2H_5OH;$$

which unites with excess of sodium to form a further quantity of alcoholate. The synthesis can actually be carried out when separately prepared sodium ethoxide is employed instead of metallic sodium, the yield being only slightly inferior (*Claisen*, private communication). Sodium amide can also be employed (B. **35**, 2321; **38**, 694).

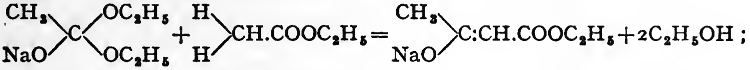
If, however, sodium be made to act on the ester in ether or benzene solution, there results the sodium salt of an acyloïn (p. 341). On the directive influence on the course of reaction exerted by the nature of the solvent, see C. 1907, II. 30.

The first step in the synthesis can be taken as being the formation of a compound:

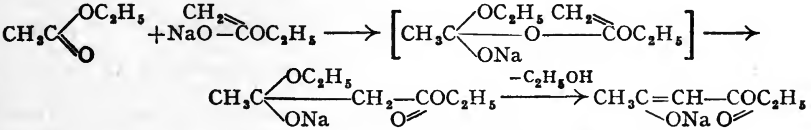


$$\begin{matrix}CH_3\\NaO\end{matrix}\!>\!C\!<\!\begin{matrix}OC_2H_5\\OC_2H_5\end{matrix} \quad\text{or}\quad \begin{matrix}CH_3\\NaO\end{matrix}\!\gg\!COC_2H_5$$

(the latter perhaps resulting from the former by the loss of alcohol). The ortho-derivative then reacts with the still unchanged ester:



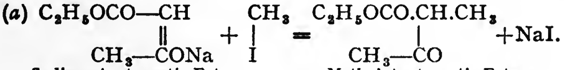
or else, a molecule of the ester and a molecule of the sodium ester unite and then split off alcohol:



(Comp. *Claisen* and *Michael*, A. **297**, 92; B. **36**, 3678; **38**, 714, 1934.) Both assumptions coincide equally well with the fact that fatty acid esters do not condense, analogously to the above, with secondary and tertiary alkyl groups.

(2) The interaction between the sodium compound of acetoacetic ester, and of mono-ethyl acetoacetic ester, with alkyl halides, especially the iodide and bromide, results in the formation of homologous esters.

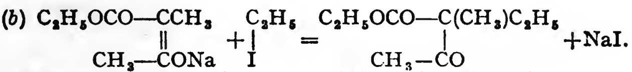
An examination of the structural formula for the acetoacetic ester reveals that only *one* hydrogen is replaceable by sodium. The metallic compound reacts with the halogen alkyl, whereby the sodium salt is formed and the alkyl group becomes attached to the α-C atom.



$$(a)\ \begin{matrix}C_2H_5OCO—CH\\ \Vert\\ CH_3—CONa\end{matrix} + \begin{matrix}CH_3\\ \vert\\ I\end{matrix} = \begin{matrix}C_2H_5OCO.CH.CH_3\\ \vert\\ CH_3—CO\end{matrix} + NaI.$$

Sodium Acetoacetic Ester. α-Methyl Acetoacetic Ester.

The mono-alkyl substituted ester can take up an atom of sodium and again react as above:



$$(b)\ \begin{matrix}C_2H_5OCO—CCH_3\\ \Vert\\ CH_3—CONa\end{matrix} + \begin{matrix}C_2H_5\\ \vert\\ I\end{matrix} = \begin{matrix}C_2H_5OCO—C(CH_3)C_2H_5\\ \vert\\ CH_3—CO\end{matrix} + NaI.$$

α-Methyl Sodium Acetoacetic Ester. Methyl Ethyl Acetoacetic Ester.

The α-dialkyl acetoacetic esters do not take up a further quantity of sodium.

Preparation of Acetoacetic Ester and the Alkyl Acetoacetic Esters.—Sixty parts of metallic sodium are gradually dissolved in 2000 parts of pure ethyl acetic ester, and the excess of the latter is distilled off. On cooling, the mass solidifies to a mixture of sodium acetoacetic ester and sodium ethoxide. The remaining liquid is mixed with acetic acid (50 per cent.) in slight excess. The oil separated and floating on the surface of the water is siphoned off, dehydrated with calcium chloride, and fractionated (A. **186**, 214, and **213**, 137). For the preparation of the dry sodium compound, see A. **201**, 143.

For the preparation of the alkyl acetoacetic esters according to the second method, it is not necessary to prepare pure sodium compounds. To the acetoacetic ester dissolved in 10 times its volume of absolute alcohol, is added an equivalent amount of sodium and then the alkyl iodide, after which heat is applied. To introduce a second alkyl an equivalent quantity of the sodium alcoholate and the alkyl iodide are again employed (A. **186**, 220; **192**, 153; C. 1904, II. 309). In some cases sodium hydroxide may be substituted for sodium ethoxide in these syntheses (A. **250**, 123; comp. B. **33**, 2679).

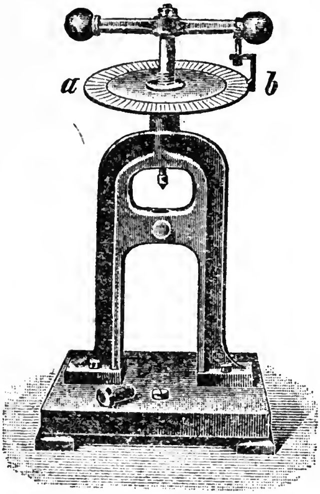


FIG. 11.

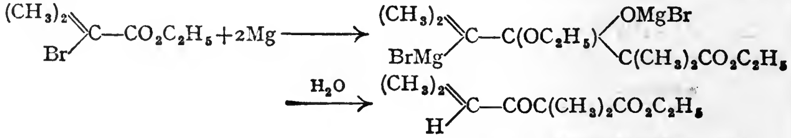
Or, sodium may be allowed to act on the sodium acetoacetic ester dissolved in some indifferent solvent, *e.g.* ether, benzene, toluene, xylene. To get the sodium in a finely divided form, so that it may act with a perfectly untarnished surface, it is forced through a sodium press (Fig. 11) into the diluent or solvent. In order that a known quantity of sodium wire shall be employed, a finely-divided and adjustable brass scale is attached to the frame of the press, whilst the plunger carries a pointer. After the quantity of sodium expressed corresponding with the division on the scale, has once and for all been determined, the amount of metal employed can always be controlled. (*H. Meerwein* and *G. Schroeter*, private communication; also *Kossel*, C. 1902, II. 718.) The choice of the indifferent solvent depends on the greater or less difficulty with which the halogen atom is displaced. In many such reactions it is necessary to heat the substances together for days at the boiling point of the solvent (comp. A. **259**, 181).

(3) The C-acyl acetoacetic ester can be employed in the formation of homologous acyl esters; it is carefully heated with alkali, whereby an acetyl group is split off (C. 1902, II. 1410):

$$\underset{\text{C-Butyl Acetoacetic Ester.}}{CH_3CH_2CH_2COCH(COCH_3)COOR} \xrightarrow{NaOH} \underset{\text{Butyl Acetic Ester.}}{CH_3CH_2CH_2COCH_2CO_2R.}$$

The action of iodo-alkyl and sodium acoholate on the C-acyl acetoacetic ester is to split off the acetyl group as acetic ester and replace it by alkyl (C. 1904, II. 25).

(4) A further general method for the synthesis of β-ketone-acid esters consists in the action of magnesium on a-bromo-fatty acid esters in ethereal solution (B. **41**, 589, 354):



$$\left.\begin{matrix}(CH_3)_2\\ Br\end{matrix}\right\rangle C{-}CO_2C_2H_5+2Mg \longrightarrow \left.\begin{matrix}(CH_3)_2\\ BrMg\end{matrix}\right\rangle C{-}C(OC_2H_5)\left\langle\begin{matrix}OMgBr\\ C(CH_3)_2CO_2C_2H_5\end{matrix}\right.$$

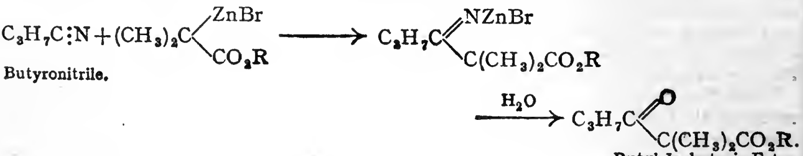
$$\xrightarrow{H_2O} \left.\begin{matrix}(CH_3)_2\\ H\end{matrix}\right\rangle C{-}COC(CH_3)_2CO_2C_2H_5$$

Isobutyl Isobutyric Ester.

$$+MgBr_2+MgO=C_2H_3OH.$$

(5) A further synthesis depends on the action of *metallo-organic* compounds on *nitriles*:

(*a*) Acid nitriles are condensed with α-bromo-fatty esters by zinc, and the product is decomposed with water (C. 1901, I. 724):



$$C_3H_7C{\vdots}N+(CH_3)_2C\left\langle\begin{matrix}ZnBr\\ CO_2R\end{matrix}\right. \longrightarrow C_3H_7C\left\langle\begin{matrix}NZnBr\\ C(CH_3)_2CO_2R\end{matrix}\right.$$

Butyronitrile.

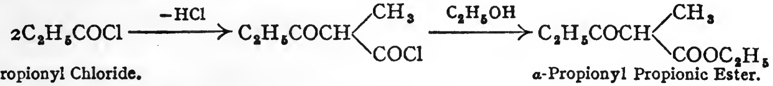
$$\xrightarrow{H_2O} C_3H_7C\left\langle\begin{matrix}O\\ C(CH_3)_2CO_2R.\end{matrix}\right.$$

Butyl Isobutyric Ester.

(*b*) The condensation of cyanacetic ester with magnesium alkyl iodides and subsequent action of water also produces β-ketone-acid esters (C. 1901, I. 1195):

$$\underset{\text{Cyanacetic Ester.}}{N\vdots CCH_2CO_2R} \xrightarrow{IMgC_2H_5} C_2H_5C(:NMgI)CH_2CO_2R \xrightarrow{H_2O} \underset{\text{Propionyl Acetic Ester.}}{C_2H_5COCH_2CO_2R.}$$

(6) The higher esters can also be prepared by the action of ferric chloride on acid chlorides, whereby a ketonic acid chloride is first formed. Water causes the loss of CO_2, forming a *ketone* (p. 218), but the action of alcohol is to produce the *ketonic acid ester* (*Hamonet*, B. **22**, R. 766):



$$2C_2H_5COCl \xrightarrow{-HCl} C_2H_5COCH\begin{cases}CH_3\\COCl\end{cases} \xrightarrow{C_2H_5OH} C_2H_5COCH\begin{cases}CH_3\\COOC_2H_5\end{cases}$$

Propionyl Chloride. α-Propionyl Propionic Ester.

The higher chlorides, such as butyryl and œnanthylic, can be employed in this reaction.

(7) When α-acetylene carboxylic acids are boiled with alcoholic potassium hydroxide, water is taken up and β-acyl acetic acids result. By esterification with alcohol and mineral acids at 0°, the β-ketonic acid esters are formed (C. 1903, I. 1018):

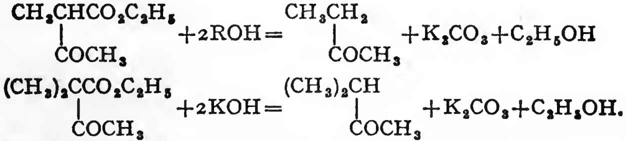
$$\underset{\text{Hexyl Propiolic Acid.}}{C_6H_{13}C{\equiv}C.CO_2H} \xrightarrow{H_2O} C_6H_{13}CO.CH_2CO_2H \longrightarrow \underset{\text{Hepto-acetic Ester.}}{C_6H_{13}CO.CH_2COOC_2H_5}$$

(8) Finally, certain syntheses have been performed, in isolated cases, from aldehydes and diazoacetic ester (p. 405) (B. **40**, 3000):

$$CCl_3CHO+N_2CHCO_2C_2H_5 \longrightarrow CCl_3CO.CH_2CO_2C_2H_5+N_2.$$

Reactions of the β-Ketonic Esters.

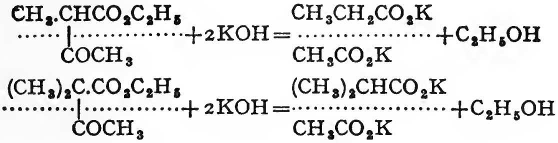
(1*a*) On heating the mono- or di-alkyl acetoacetic esters with alkalis in *dilute* aqueous or alcoholic solution, or with barium hydroxide, they decompose after the manner of acetoacetic esters (p. 417), forming ketones (alkyl acetones) (*ketone decomposition*):



$$\begin{array}{l}CH_3CHCO_2C_2H_5\\ \quad|\\ \quad COCH_3\end{array} +2ROH= \begin{array}{l}CH_3CH_2\\ \quad|\\ \quad COCH_3\end{array} +K_2CO_3+C_2H_5OH$$

$$\begin{array}{l}(CH_3)_2CCO_2C_2H_5\\ \qquad|\\ \qquad COCH_3\end{array} +2KOH= \begin{array}{l}(CH_3)_2CH\\ \qquad|\\ \qquad COCH_3\end{array} +K_2CO_3+C_2H_5OH.$$

(1*b*) At the same time another cleavage takes place, by which mono- and di-alkylacetic acids are formed along with acetic acid (*acid decomposition*):



$$\begin{array}{l}CH_3.CHCO_2C_2H_5\\ \cdots\cdots|\cdots\cdots\cdots\cdots\\ \quad COCH_3\end{array} +2KOH= \begin{array}{l}CH_3CH_2CO_2K\\ \cdots\cdots\cdots\cdots\cdots\cdots\\ CH_3CO_2K\end{array} +C_2H_5OH$$

$$\begin{array}{l}(CH_3)_2C.CO_2C_2H_5\\ \cdots\cdots\cdots|\cdots\cdots\cdots\cdots\\ \qquad COCH_3\end{array} + 2KOH= \begin{array}{l}(CH_3)_2CHCO_2K\\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\\ CH_3CO_2K\end{array} +C_2H_5OH$$

Both of these reactions, in which decomposition occurs (the cleavage of ketone and of acid), usually take place simultaneously. In using dilute potassium or barium hydroxide solution, the ketone-decomposition predominates, whereas, with very concentrated alcoholic potassium hydroxide, the acid-decomposition mainly takes place (*J. Wislicenus*, A. **190**, 276). The production of ketone, with elimination of CO_2, occurs almost exclusively on boiling with sulphuric or hydrochloric acid (1 part acid and 2 parts water).

This breaking-down of the mono- and di-alkyl acetoacetic esters is the basis of the application of these bodies in the production of mono- and di-alkyl acetones (p. 218), as well as mono- and dialkyl acetic acids.

(1*c*) The decomposition of mono- and di-alkyl-acetoacetic esters into mono- and di-acetic esters can be carried out directly and completely by boiling with sodium ethoxide solution (*ester decomposition*) (B. **33,** 2670 ; **41,** 1260) :

$$CH_3CO.C(CH_3)_2CO_2R + ROH = CH_3CO_2R + (CH_3)_2CHCO_2R.$$

(2) The acetoacetic esters are converted by nascent hydrogen (sodium amalgam) into the corresponding β-hydroxy-acids (p. 358) :

$$CH_3CO.CH_2CO_2C_2H_5 + H_2 + H_2O = CH_3CH(OH).CH_2CO_2H + C_2H_5OH.$$

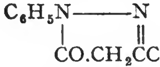
They are hydrolyzed at the same time.

(3) Chlorine and bromine produce halogen substitution products of the acetoacetic esters.

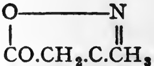
(4) PCl_5 replaces the oxygen of the β-CO group by 2 atoms of chlorine. The *chloride*, $CH_3CCl_2.CH_2COCl$, readily loses hydrochloric acid and yields two chlorocrotonic acids (p. 295).

(5) Orthoformic ester replaces the oxygen of the β-CO group by two ethoxy-groups producing β-diethyl butyric ester, which readily splits off alcohol and yields β-ethoxycrotonic ester (p. 418).

(6) Ammonia, aniline, hydrazine and phenylhydrazine acting on acetoacetic ester produce the imine, anilide, hydrazone and phenylhydrazone, which can also be looked on as being respectively β-amino-, β-anilino-, β-hydrazino-, and β-phenylhydrazino-crotonic esters. The acetoacetic ester forms the semicarbazide with semicarbazone, and the oxime with hydroxylamine (B. **28,** 2731). The hydrazones and oximes of the β-ketonic esters easily give up alcohol and become converted into cyclic derivatives—*lactazams* and *lactazones* (comp. p. 406), usually known as *pyrazolones* and *isoxazoles* :



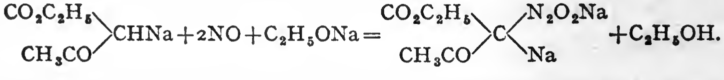
Phenyl Methyl Pyrazolone.



Methyl Isoxazole.

One molecule of hydrazine converts acetoacetic ester into the *azine*, $(C_6H_{10}O_2) : N-N : (C_6H_{10}O_2)$, m.p. 48°, which an excess of hydrazine easily transforms into two molecules of methyl pyrazolone (B. **37,** 2820 ; **38,** 3036).

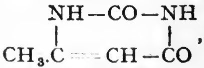
(7) Nitric oxide and sodium ethoxide change sodium acetoacetic ester into the disodium derivative of isonitramine acetoacetic ester (A. **300,** 89) :



(8) Nitrous acid changes the non-alkylated acetoacetic ester to the isonitroso-derivatives, $CH_3CO.C(N.OH)CO_2R$, which readily break up into isonitroso-acetone, CO_2 and alcohols (see below). Nitrous acid, acting on mono-alkyl acetoacetic esters, displaces the acetyl group and leads to the formation of α-isonitroso-fatty acids (p. 410), whereas the free monoalkyl acetoacetic esters, under like treatment, split off CO_2 and yield isonitroso-ketones (p. 354).

(9) Benzene diazo-salts act on acetoacetic ester similarly to nitrous acid (B. **21,** 549 ; A. **247,** 217).

(10) Diazomethane converts acetoacetic ester into β-methoxy-crotonic ester (p. 418) (B. **28,** 1626).

(11) An important reaction is the union of acetoacetic ester with urea, when water is eliminated and **Methyl Uracil,**  , is formed. This is the parent substance in the synthesis of uric acid (*q.v.*).

(12) Amidines convert acetoacetic ester into pyrimidine compounds (Vol. II.).

(13) The action of sulphur chloride or thionyl chloride on acetoacetic ester is to produce thiodiacetoacetic ester $S[CH(COCH_3)CO_2C_2H_5]_2$ (B. **39**, 3255).

Nucleus-synthetic Reactions.

(1) Heated alone, acetoacetic ester is changed to dehydracetic acid (*q.v.*), the δ-lactone of an unsaturated δ-hydroxy-diketone carboxylic acid.

(2) The action of sulphuric acid causes acetoacetic ester to pass into a condensation product, isodehydracetic acid, the δ-lactone of an unsaturated δ-hydroxy-dicarboxylic acid.

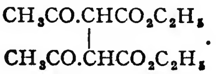
(3) Hydrocyanic acid unites with acetoacetic ester, forming the nitrile of α-methyl malic ester.

(4) (For the action of magnesium alkyl iodides on acetoacetic ester, comp. C. 1902, I. 1197.)

The nucleus-synthetic reactions of sodium acetoacetic ester and copper acetoacetic ester are far more numerous.

(5) It has been repeatedly mentioned that the sodium acetoacetic esters could be applied in the building-up of the mono- and di-alkyl acetoacetic esters, and also, therefore, in the preparation of mono- and di-alkyl acetones, as well as mono- and di-alkyl acetic acids.

(6) Iodine converts sodium acetoacetic ester into diacetosuccinic ester:



$$\begin{array}{l} CH_3CO.CHCO_2C_2H_5 \\ \quad\quad\quad\ \ | \\ CH_3CO.CHCO_2C_2H_5 \end{array}.$$

This body is also produced in the electrolysis of sodium acetoacetic ester (B. **28**, R. 452).

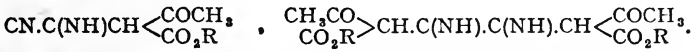
(7) Chloroform and sodium acetoacetic ester unite to form hydroxyuvitic acid, $C_6H_2(CH_3)(OH)(CO_2H)_2$.

(8) Furthermore, *monochloracetone, cyanogen chloride, acid halides,* and *monohalogen substitution products of mono- and di-carboxylic esters* react with sodium acetoacetic ester. *Copper acetoacetic ester* is most advantageously used with phosgene (B. **19**, 19). (For greater detail see below.)

(9) Aldehydes, *e.g.* acetaldehyde, and acetoacetic ester unite to form ethylidene mono- and ethylidene bisacetoacetic esters. The latter γ-diketones especially are important, because by an intramolecular change, causing the loss of water from CO and CH_3, they condense to keto-hydrobenzene derivatives (A. **288**, 323), and with ammonia yield hydropyridine bodies. *Acetone* condenses with acetoacetic ester, forming isopropylidene acetoacetic ester (p. 425) (B. **30**, 481).

(10) Acetoacetic ester condenses similarly with orthoformic ester to the ethoxymethylene derivative $(C_6H_8O_2):CHOC_2H_5$, and to the methylene derivative $(C_6H_9O_3):CH.(C_6H_9O_3)$ (B. **26**, 2729).

(11) *Dicyanogen* unites with sodium acetoacetic ester, forming the sodium compound of ***α-acetyl β-cyano-β-iminopropionic ester,*** and of ***α₁α-diacetyl β₁β-diimino-adipic ester*** (B. **35**, 4142):



$$CN.C(NH)CH{<}\begin{matrix}COCH_3\\CO_2R\end{matrix}\quad , \quad \begin{matrix}CH_3CO\\CO_2R\end{matrix}{>}CH.C(NH).C(NH).CH{<}\begin{matrix}COCH_3\\CO_2R\end{matrix}.$$

(12) *Phenols* condense with acetoacetic ester to form coumarines (Vol. II.) (B. **29**, 1794); *quinones* (Vol. II.) form cumarones.

Acetoacetic Ethyl Ester, *Acetoacetic Ester,* $C_6H_{10}O_3=CH_3CO.CH_2CO_2C_2H_5$, b.p.$_{760}$ 181°, b.p.$_{12}$ 72°, is a pleasantly smelling liquid, $D_{20}=1{\cdot}0256$. The ester is only slightly soluble in water, it distils readily in steam. Ferric chloride colours it violet.

Boiling alkalis or acids convert the ester into acetone, carbon dioxide and alcohol. In addition to its formation by the action of sodium, sodium amide, or sodium ethoxide on acetic ethyl ester, it results by the partial decomposition of *acetone dicarboxylic ester* (*q.v.*), $CO_2C_2H_5.CH_2COCH_2.CO_2C_2H_5$.

Acetoacetic Methyl Ester, b.p. 169°.

The *sodium salt*, $CH_3(CONa):CHCO_2C_2H_5$, crystallizes in long needles. *Copper salt*, $(C_6H_9O_3)_2Cu$, is produced when a copper acetate solution is shaken with an alcoholic solution of acetoacetic ester. When boiled with methyl alcohol, it undergoes *alcoholysis*, and is converted into $(C_6H_9O_3)CuOCH_3$ (B. **35**, 539); *aluminium salt*, m.p. 80°, b.p.$_{8}$ 194° (C. 1900, I. 11).

Homologous β-Ketonic Acid Esters:

Methyl Acetoacetic Methyl Ester . *ethyl ester*, b.p. 187°.	$CH_3COCH(CH_3)CO_2CH_3$ b.p. 169°	
Ethyl Acetoacetic Methyl Ester . *ethyl ester*, b.p. 198°.	$CH_3COCH(C_2H_5)CO_2CH_3$,, 190°	
Dimethyl Acetoacetic Ethyl Ester .	$CH_3COC(CH_3)_2CO_2C_2H_5$,, 184°	Mode of formation No. 2 (p. 413).
Methyl Ethyl Acetoacetic Ester .	$CH_3COC(CH_3)(C_2H_5)CO_2R$,, 198°	
Propyl Acetoacetic Ester . . .	$CH_3COCH(C_3H_7)CO_2R$,, 208°	
Diethyl Acetoacetic Ester . . .	$CH_3COC(C_2H_5)_2CO_2R$,, 218°	
Propionyl Acetic Ester	$CH_3CH_2COCH_2CO_2R$, b.p.$_{17}$ 92° (mode of formation 3 and 5*b*).	
Propionyl Propionic Ester . . .	$CH_3CH_2COCH(CH_3)CO_2R$, b.p. 196° (mode of formation 1, 4, and 6).	
Butyryl Acetic Methyl Ester . .	$CH_3CH_2CH_2COCH_2CO_2CH_3$, b.p.$_{14}$ 85° (mode of formation 3, 5*b*, and 7).	
Butyryl Butyric Ester	$C_3H_7COCH(C_2H_5)CO_2R$, b.p. 223° (mode of formation 4 and 6).	
Butyryl Isobutyric Ester . . .	$C_3H_7COC(CH_3)_2CO_2R$, b.p.$_{29}$ 109° (mode of formation 5*a*).	
Isobutyryl Isobutyric Ester . . .	$(CH_3)_2CHCOC(CH_3)_2CO_2R$, b.p. 203° (mode of formation 4).	
Decanoyl Acetic Ester	$C_9H_{19}COCH_2CO_2R$, b.p.$_{18}$ 165° (mode of formation 7).	

The *enol*- (*pseudo*-, *aci*-) form of the above derivatives of acetoacetic acid are to be derived from the corresponding *keto*- forms.

Ethers and Thio-ethers of the β-Ketonic Acid Esters: *β-Diethoxybutyric Ester, Ortho-ethyl Ether of Acetoacetic Ester*, $CH_3C(OC_2H_5)_2CH_2CO_2C_2H_5$, is obtained by the inter-reaction at low temperatures of acetoacetic and orthoformic esters under the influence of various reagents (comp. pp. 412, 417). It is an oil, which is converted by saponification into the crystallizable sodium salt of *β-diethoxybutyric acid*. This readily gives up CO_2, and becomes changed into acetone ortho-ethyl ether (p. 225). The diethoxybutyric acid ester decomposes on distillation into alcohol and *β-Ethoxycrotonic Ester, ethyl ether of aci-acetoacetic ester*, $CH_3C(OC_2H_5):CHCO_2C_2H_5$, m.p. 30°, b.p. 195°. This, on saponification, yields *β-Ethoxycrotonic Acid*, m.p. 137°; it can also be formed from sodium ethoxide and β-chlorocrotonic acid (p. 295), and also from acetoacetic ester. On heating, it loses CO_2 and is converted into isopropenyl ethyl ether (p. 129) (A. **219**, 327; **256**, 205). Alcoholic sodium ethoxide changes ethoxycrotonic ester back into di-ethoxybutyric ester (B. **29**, 1007). *β-Methoxycrotonic Ester*, $CH_3C(OCH_3):CHCO_2C_2H_5$, m.p. 188°, is formed from acetoacetic ester and diazomethane (B. **28**, 1627).

A mixture of the two types of ethers—the ethyl ether of the aci- form and the ortho-ether of the keto- form of the β-ketonic esters—are obtained by boiling the homologous propiolic acid ester (p. 303) with alcoholic potassium hydroxide:

$$RC:CCO_2C_2H_5 \longrightarrow RC(OC_2H_5):CHCO_2C_2H_5 \longleftrightarrow RC(OC_2H_5)_2.CH_2CO_2C_2H_5.$$

Similarly, propiolic nitrile yields the ***ether of the ketonic acid nitrile*** (C. 1904, I. 659; 1906, I. 912).

The aci-ether is readily hydrolyzed by dilute sulphuric acid into the β-ketone acid ether.

β-Dithioethyl Butyric Ester, $CH_3C(SC_2H_5)_2CH_2CO_2C_2H_5$, b.p.$_{37}$ 138°, is decomposed by hydrolysis into mercaptan and *β-Thioethyl Crotonic Acid*, $CH_3C(SC_2H_5):CHCO_2H$, m.p. 91° (B. **33**, 2801; **34**, 2634).

Esters of the aci-β-Ketonic Acid Esters.

Acid chlorides and also halogen alkyls, acting on sodium acetoacetic ester, produce mainly the C-*acyl* compounds (described later among the diketo-carboxylic esters). Some O-*acyl ester* is also formed, which can be obtained as a main product, by the action of acid chlorides on acetoacetic ester in the presence of pyridine. The O-acyl esters are insoluble in alkalis, whilst the C-acyl esters are soluble, thus providing an easy method of separation. When heated with alkalis (potassium carbonate, sodium acetoacetic ester, etc.), the O-acyl esters are transformed into C-acyl esters. By heating to 240°, O-acetyl acetoacetic ester is converted to a small extent into di-acetoacetic ester (B. **38**, 546):

$$CH_3C(OCOCH_3)=CHCO_2C_2H_5 \longrightarrow CH_3CO-CH(COCH_3)CO_2C_2H_5.$$

Chlorocarbonic ester and sodium acetoacetic ester produce almost entirely carbethoxyl hydroxycrotonic ester, whilst with the copper salt *acetyl malonic ester* is formed (B. **37**, 3394). Both sodium and copper acetoacetic esters yield *Acetyl Malonanilic Acid Ester*, $CH_3COCH(CONHC_6H_5)CO_2C_2H_5$ (B. **37**, 4627; **38**, 22). It is therefore difficult to formulate a law for the acylation of these esters.

O-Acetyl Acetoacetic Ester, β-Acetoxycrotonic Ester, $CH_3C(OCOCH_3):CHCO_2C_2H_5$, b.p.$_{12}$ 98°; *methyl ester*, b.p. 95°. *O-Butyryl Acetoacetic Methyl Ester*, b.p.$_{10}$ 105°. *O-Propionyl Acetoacetic Ethyl Ester*, b.p.$_{12}$ 106° (C. 1902, II. 1411); *O-benzoyl ester*, m.p. 43°.

O-Carboxethyl Acetoacetic Ester, β-Carboxethyl Hydroxycrotonic Ester, $CH_3C(OCO_2C_2H_5):CHCO_2C_2H_5$, b.p.$_{14}$ 131°.

Nitrogen Derivatives of β-Ketone Carboxylic Acid.

Amides.

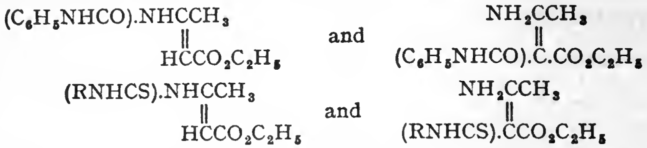
Aqueous ammonia acting on acetoacetic ester produces β-aminocrotonic ester (below), and *Acetoacetic Amide*, $CH_3COCH_2CONH_2$, m.p. 50°, which forms a crystalline copper salt (B. **35**, 583). *Methyl Acetoacetic Amide*, $CH_3CO.CH(CH_3)CONH_2$, m.p. 73°, and *Ethyl Acetoacetic Amide*, m.p. 96°, are prepared respectively from methyl and ethyl acetoacetic ester, and ammonia (A. **257**, 213). Similarly, dimethyl and methyl ethyl acetoacetic ester form *amides*, m.p. 121° and 124° respectively; di-ethyl acetoacetic ester does *not* form an amide (C. 1907, I. 401).

Nitriles.

Cyanacetone: Acetoacetic Acid Nitrile, $CH_3CO.CH_2CN$, b.p. 120–125°, is prepared from imino-acetoacetic nitrile (see below) and hydrochloric acid; also by the transformation of α-methyl isoxazole (p. 354) (B. **25**, 1787). It cannot be obtained from chloracetone and KCN. On heating it polymerizes suddenly. Chlorethyl methyl ketone and chlormethyl ethyl ketone (p. 342) do, however, react with potassium cyanide to form *a-Methyl Acetoacetic Nitrile*, $CH_3COCH(CH_3)CN$, b.p. 146° and *Propionyl Acetonitrile*, $CH_3CH_2COCH_2CN$, b.p. 165° (C. 1900, I. 1123; 1901, I. 96).

The reaction of aniline, hydrazine, phenylhydrazine and semicarbazide, hydroxylamine, nitrous acid, nitric oxide, diazomethane, benzene, diazo-salts, urea and the amidines, with β-keto-carboxylic esters are comparable to those on pp. 416, 417 (Nos. 6–13), in which the formation of pyrozalones or lactazams from the β-keto-acid esters and the hydrazines is again to be remarked; see Phenyl Methyl Pyrazolone and Antipyrine (Vol. II.). A more detailed description is given in connection with aminocrotonic ester.

β-Aminocrotonic Ester or *Imino-acetoacetic Ester*, $CH_3C(NH_2):CHCO_2C_2H_5$, or $CH_3C(NH)CH_2CO_2C_2H_5$, two modifications, m.ps. 20° and 33° (A. **314**, 202), is prepared from acetoacetic ester or β-chlorocrotonic ester (p. 295) and ammonia (B. **28**, R. 927). Aqueous hydrochloric acid converts it back into acetoacetic ester. Hydrochloric acid gas forms a salt which is decomposed by heat at 130° into ammonium chloride and δ-olefine lactone carboxylic ester, *pseudo-lutidostyril carboxylic ester* (B. **20**, 445; A. **236**, 292; **259**, 172). NaClO and NaBrO produce *chlor-* and *brom-amino- crotonic ester*, $CH_3C(NHX):CHCO_2R$, which, on treatment with acids, lose NH_3, and are converted into α-chlor- and α-bromacetoacetic ester (A. **318**, 371). On the action of nitrous acid, see B. **37**, 47. Phenyl cyanate and mustard oil combine with aminocrotonic ester, and form a series of N- and C- derivatives (A. **314**, 209; **344**, 19):



$$\begin{array}{r} (C_6H_5NHCO).NHCCH_3 \\ \| \quad\;\; \\ HCCO_2C_2H_5 \end{array} \text{ and } \begin{array}{c} NH_2CCH_3 \\ \| \\ (C_6H_5NHCO).C.CO_2C_2H_5 \end{array}$$

$$\begin{array}{r} (RNHCS).NHCCH_3 \\ \| \quad\;\; \\ HCCO_2C_2H_5 \end{array} \text{ and } \begin{array}{c} NH_2CCH_3 \\ \| \\ (RNHCS).CCO_2C_2H_5 \end{array}$$

β-Aminocrotonic Acid Nitrile, Imino-acetoacetic Nitrile, $CH_3C(NH_2):CHCN$ or $CH_3C(NH).CH_2CN$, m.p. 52°, results from the condensation of two molecules of acetonitrile by means of metallic sodium (J. pr. Ch. [2] **52**, 81).

Homologous *β-alkylamino-* and *β-di-alkylamino-acrylic esters,* $(C_2H_5)_2NCR:CCO_2C_2H_5$, and *nitriles,* $C_2H_5CH_2NHCR:CHCN$, are prepared by the addition of amines to the homologous propiolic esters and nitriles. Acids easily decompose them into the β-ketonic acid esters or nitriles, and amines (C. 1907, I. 25). *Dinitrocaproic Acid,* $CH_3C(NO_2)_2C(CH_3)_2CO_2H$, m.p. 215° with decomposition, is formed when camphor is boiled for a long time with nitric acid. It can be looked on as being a derivative of α-dimethyl acetoacetic acid (B. **26**, 3051).

Halogen Substitution Products of the β-Ketonic Esters.

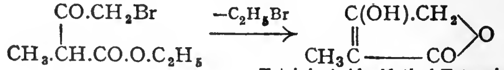
Chlorine alone or in the presence of sulphuryl chloride acting on acetoacetic ester replaces the hydrogen atoms both of the CH_2 and CH_3 groups by chlorine. The hydrogen of the CH_2 group is first substituted.

α-Chloracetoacetic Ester, $CH_3COCHClCO_2C_2H_5$, b.p.$_{10}$ 109°, possesses a penetrating odour. *γ-Chloracetoacetic Ester,* $ClCH_2COCH_2CO_2C_2H_5$, b.p.$_{11}$ 105°, is prepared by the oxidation of γ-chloro-β-hydroxybutyric ester with chromic acid; also synthetically, from chloroacetic ester and aluminium amalgam (comp. method of formation 4, p. 414). *Copper salt,* m.p. 168° with decomposition, forms green crystals (C. 1904, I. 788; 1907, I. 944). *α-Bromacetoacetic Ester,* $CH_3CO.CHBr.CO_2C_2H_5$, b.p.$_{12}$ 101–104°, is obtained from acetoacetic ester and bromine in the cold (B. **36**, 1730). HBr converts it gradually into *γ-Bromacetoacetic Ester,* $CH_2Br.CO.CH_2CO_2C_2H_5$, b.p.$_9$ 125° (B. **29**, 1042). This substance is also formed from bromacetic ester and magnesium (B. **41**, 954).

The constitution of these two bodies has been established by condensing them with thiourea to the corresponding thiazole derivatives.

αα-Dichloracetoacetic Ester, $CH_3COCCl_2CO_2C_2H_5$, b.p. 205°, is a pungent-smelling liquid. Heated with HCl it decomposes into α-dichloracetone, $CH_3COCHCl_2$, alcohol, and CO_2; with alkalis it yields acetic and dichloracetic acids. *αα-Dibromacetoacetic Ester* is a liquid; *dioxime,* $CH_3C(NOH)C(NOH)CO_2C_2H_5$, m.p. 142°. *αγ-Dibromacetoacetic Ester,* $CH_2Br.CO.CHBr.CO_2C_2H_5$, m.p. 45–49°.

According to *Demarçay* (B. **13**, 1479, 1870) the γ-mono-bromo-mono-alkyl-acetoacetic esters, when heated alone or with water, split off ethyl bromide and yield peculiar acids; thus, bromomethyl acetoacetic ester gave *Tetrinic Acid* or *Methyl Tetronic Acid,* whilst bromethyl acetoacetic ester yielded *Pentinic Acid* or *Ethyl Tetronic Acid* (L. *Wolff,* A. **291**, 226):

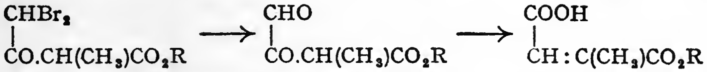


Tetrinic Acid=Methyl Tetronic Acid.

These acids will be discussed later as lactones of hydroxy-ketonic acids, together with the oxidation products of triacid alcohols.

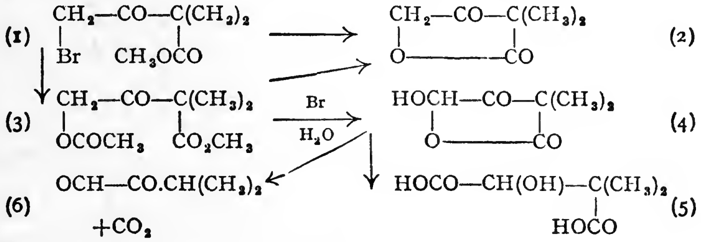
The *γ-dibromo-mono-alkyl acetoacetic esters,* treated with alcoholic potassium hydroxide, yield hydroxytetrinic acid, hydroxypentinic acid, etc. *Gorbow* (B. **21**, R. 180) found them to be homologues of fumaric acid. Hydroxytetrinic acid is mesaconic acid (*q.v.*); whilst hydroxypentinic acid is ethyl fumaric acid (*q.v.*), etc.

The formation of these olefine dicarboxylic acids from γγ-dibromo-mono-alkyl acetoacetic esters is easily explained on the assumption that the keto- or aldehyde acids are first formed, which are then converted into the unsaturated dicarboxylic acids:



$$\begin{matrix} CHBr_2 \\ | \\ CO.CH(CH_3)CO_2R \end{matrix} \longrightarrow \begin{matrix} CHO \\ | \\ CO.CH(CH_3)CO_2R \end{matrix} \longrightarrow \begin{matrix} COOH \\ | \\ CH:C(CH_3)CO_2R \end{matrix}$$

The γ-bromo-dialkyl acetoacetic esters, however, behave differently, giving rise to lactones of γ-hydroxy-β-ketone carboxylic acids (*Conrad* and *Gast*). The bromine atom of the *γ-bromo-dimethyl-acetoacetic ester* (1, see diagrammatic representation below), can be replaced by acetoxyl (2), producing the γ-acetoxy-dimethyl-acetoacetic ester, which gives up methyl acetate and changes into *γ-hydroxy-dimethyl-acetoacetic acid lactone* (3). Bromine, entering the molecule of the γ-acetoxy-dimethyl-acetoacetic ester, becomes attached to the γ-carbon atom, producing a compound which has not been isolated. The action of water on this is the immediate production of the *lactone* of *γ-dihydroxy-dimethyl-acetoacetic acid* (4). Its salts are those of an aldehyde-ketone-carboxylic acid, which is converted by alkalis into *β-dimethyl malic acid* (5); whilst on fusion a keto-aldehyde—*isobutyryl formaldehyde* (p. 348)—is formed (6). The inter-relations of these compounds are shown as follows (B. **31**, 2726, 2954):

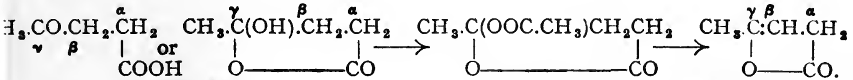


The action of ammonia on γ-bromo-dimethyl-acetoacetic ester is to form the lactam of γ-amino-dimethyl-acetoacetic acid—dimethyl ketopyrrolidone—which is broken down by hydrochloric acid into amino-dimethyl-acetone (p. 344) (B. **32**, 1199).

γ-Trichloracetoacetic Ester, $CCl_3COCH_2CO_2C_2H_5$, b.p. 234°, is also prepared synthetically from chloral and diazoacetic ester (p. 404) (B. **40**, 3001).

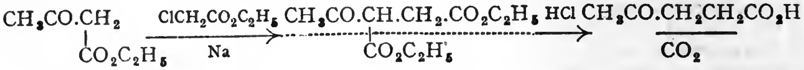
III. γ-Ketonic Acids.

These acids are distinguished from the acids of the β-variety by the fact that when heated they do not yield CO_2, but split off water and pass into unsaturated γ-lactones. They form γ-hydroxy-acids on reduction, which readily pass into saturated γ-lactones. An interesting fact in this connection is that they yield remarkably well crystallized acetyl derivatives when treated with acetic anhydride. This reaction, as well as the production of unsaturated γ-lactones, on distillation, argues for the view that the γ-ketonic acids are γ-oxy-lactones:



Lævulinic Acid. Acetyl Lævulinic Acid. α-Angelica Lactone.

Lævulinic Acid, β-Acetopropionic Acid, *γ-Ketovaleric Acid,* or *γ-Oxovaleric Acid* [4-Pentanone Acid], $C_5H_8O_3=CH_3.CO.CH_2.CH_2.CO_2H$, or $CH_3.\overset{|}{C}(OH).CH_2.CH_2CO\overset{|}{O}$, m.p. 32·5°; b.p.$_{12}$ 144°, b.p.$_{760}$ 239° with slight decomposition, is isomeric with methyl acetoacetic acid, which may be designated α-acetopropionic acid. Lævulinic acid can be obtained from the *hexoses* (*q.v.*) on boiling them with dilute hydrochloric or sulphuric acid. It is more easily obtained (1) from lævulose—hence the name—than from dextrose. It is prepared by heating sucrose or starch with hydrochloric acid (B. **19,** 707, 2572; **20,** 1775; A. **227,** 99). Its constitution is evident from its direct and also indirect syntheses; (2) from the mono-ethyl ester of succinyl monochloride, $ClCO.CH_2.CH_2CO_2C_2H_5$, and zinc methyl (C. 1899, II. 418); and by boiling the reaction-product of chloracetic ester and sodium acetoacetic ester—acetosuccinic ester—with hydrochloric acid or barium hydroxide solution (*Conrad*, A. **188,** 223):



$$\underset{\displaystyle CO_2C_2H_5}{CH_3CO.CH_2} \xrightarrow[Na]{ClCH_2CO_2C_2H_5} CH_3CO.\underset{\displaystyle CO_2C_2H_5}{CH}.CH_2.CO_2C_2H_5 \xrightarrow{HCl} CH_3CO.\underset{CO_2}{\underline{CH_2CH_2CO_2H}}$$

It is furthermore obtained (3) by the action of concentrated H_2SO_4 on methyl glutolactonic acid, $CH_3\overline{C(CO_2H)CH_2CH_2COO}$; (4) by the oxidation of its corresponding β-acetopropyl alcohol (p. 342), (5) by the oxidation of methyl heptenone (p. 232), of linalool and geraniol, two bodies belonging to the group of olefine terpenes. Also, by hydrolysis of crotonaldehyde cyanohydrin with warm hydrochloric acid and the transformation of the propenyl glycollic acid thus formed (p. 397).

Lævulinic acid dissolves very readily in water, alcohol and ether, and undergoes the following changes: (1) By slow distillation under the ordinary pressure it breaks down into water and α- and β- angelic lactones (p. 398). (2) When heated to 150–200° with hydriodic acid and phosphorus, lævulinic acid is changed to n-valeric acid. (3) By the action of sodium amalgam sodium γ-hydroxyvalerate is produced, the acid from which changes into γ-valerolactone. (4) Dilute nitric acid converts lævulinic acid partly into acetic and malonic acid and partly into succinic acid and carbon dioxide. The action of sunlight on an aqueous solution of the acid is to produce a certain quantity of methyl alcohol, formic and propionic acids (B. **40,** 2417).

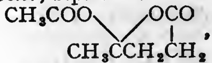
(5) Bromine converts the acid into substitution products (p. 423).

(6) Iodic acid changes it to *bi-iodo-acetacrylic acid.* (7) P_2S_3 converts it into *thiotolene*, $C_4H_3S.CH_3$ (Vol. II.). For the behaviour of lævulinic acid with hydroxylamine and phenylhydrazine consult the paragraph relating to the nitrogen derivatives of the γ-ketonic acids.

Nucleus-synthetic Reactions: (8) Hydrocyanic acid and lævulinic acid yield the nitrile of methyl glutolactonic acid: $CH_3.\overline{C(CN)CH_2CH_2COO}$ (see above). (9) Benzaldehyde and lævulinic acid condense in acid solution to *β-benzal lævulinic acid*, and in alkaline solution to *δ-benzal lævulinic acid* (A. **258,** 129; B. **26,** 349). 10) Electrolysis of potassium lævulinate results in the production of 1,4-diacetyl butane (p. 352) (B. **33,** 155).

Lævulinic Acid Derivatives.—The *calcium salt*, $(C_5H_7O_3)_2Ca+2H_2O$; *silver salt*, $C_5H_7O_3Ag$, is a characteristic, crystalline precipitate, dissolving in water with difficulty; *methyl ester*, $C_5H_7(CH_3)O_3$, b.p. 191°; *ethyl ester*, b.p. 200°.

Acetyl Lævulinic Acid, γ-Acetoxyl, γ-Valerolactone,



, m.p. 78°, is particularly noteworthy. It is formed from lævulinic acid and acetic anhydride; from silver lævulinate and acetyl chloride; from lævulinic chloride and silver acetate; as well as from α-angelic lactone and acetic acid. The last method of formation, as well as the formation of α- and β-angelic lactone by heating acetolævulinic acid are most easily understood upon the assumption that the constitution is really as indicated in the formula shown above (A. **256**, 314).

Lævulinic Chloride, γ-Chlorovalerolactone, $CH_3CClCH_2CH_2COO$, b.p.$_{15}$ 80°, is produced by the addition of HCl to α-angelic lactone, and by the action of acetyl chloride on lævulinic acid (A. **256**, 334). *Lævulinamide, γ-Amidovalerolactone,* $CH_3C(NH_2)CH_2CH_2COO$, has been obtained from lævulinic ester, and from α-angelic lactone and ammonia (A. **229**, 249).

Homologous Lævulinic Acids are obtained from the homologues of acetosuccinic ester (p. 422):

β-Methyl Lævulinic Acid, β-Acetobutyric Acid, $CH_3CO.CH(CH_3)CH_2CO_2H$, m.p. −12°, b.p. 242°, is prepared from α-methyl acetosuccinic ester. It forms a difficultly soluble semicarbazone (C. 1900, II. 242), *α-Methyl Lævulinic Acid, β-Acetyl Isobutyric Acid,* $CH_3CO.CH_2CH(CH_3)CO_2H$, m.p. 248°. *Homolævulinic Acid, δ-Methyl Lævulinic Acid,* $CH_3CH_2CO.CH_2CH_2COOH$, m.p. 32°, is obtained from βγ-dibromocaproic acid (A. **268**, 69), together with one of the hydroxy-caprolactones, *α-Ethyl Lævulinic Acid,* $CH_3CO.CH_2CH(C_2H_5)CO_2H$, m.p. 250–252°.

Mesitonic Acid, αα-Dimethyl Lævulinic Acid, $CH_3CO.CH_2C(CH_3)_2CO_2H$, m.p. 74°, b.p.$_{15}$ 138°, is obtained by the action of alcoholic potassium cyanide solution on mesityl oxide, $CH_3COCH:C(CH_3)_2$ (p. 229). The *nitrile,* $CH_3COCH_2(CH_3)_2CN$, is formed as an intermediate product, and can be formed from mesityl oxide hydrochloride by KCN. Mesityl oxide and hydrocyanic acid in excess produce the cyanhydrin of mesitonic nitrile, the dinitrile of the so-called mesitylic acid, which decomposes on being heated with hydrochloric acid into formic and mesitonic acids (C. 1904, II. 1108; B. **37**, 4070; A. **247**, 90). Mesitonic acid is converted into dimethyl malonic acid when oxidized with nitric acid.

ββ-Dimethyl Lævulinic Acid, $CH_3COC(CH_3)_2.CH_2CO_2H$, b.p.$_{18}$ 151°, results from α-unsym.-dimethyl succinyl chloride and zinc methyl (C. 1899, II. 524).

δδ-Dimethyl Lævulinic Acid, $(CH_3)_2CH.CO.CH_2CH_2CO_2H$, m.p. 40°, is prepared from the result of the double decomposition of γ-bromo-dimethyl-acetoacetic ester and sodium malonic ester, by heating it with dilute sulphuric acid (B. **30**, 864); by oxidation of dimethyl acetonyl acetone (p. 252) (B. **31**, 2311); from dibrom-isoheptoic acid and soda solution (A. **288**, 133); by oxidation of various terpenes (Vol. II.), such as thujone.

βδ-Dimethyl Lævulinic Acid, $CH_3CH_2COCH(CH_3)CH_2COOH$, b.p. 154°, is produced from γ-ethylidene β-methyl butyrolactone, a degradation product of dicrotonic acid (*q.v.*); also by the splitting up of αα-dimethyl acetone dicarboxylic α-acetic ester (B. **33**, 3323).

Caproyl Isobutyric Acid, $C_5H_{11}COCH_2CH(CH_3)CO_2H$, m.p. 33°, b.p.$_{23}$ 190° (C. 1905, II. 1782).

Halogen γ-Ketonic Acids.—*α-Bromolævulinic Acid,* $CH_3COCH_2CHBrCO_2H$, m.p. 79°, is produced when HBr acts on β-acetoacrylic acid. Boiling water converts it into α-hydroxylævulinic acid (*q.v.*).

β-Bromolævulinic Acid, $CH_3COCHBrCH_2CO_2H$, m.p. 59°, is produced in the bromination of lævulinic acid, as well as by the action of water on the addition product of bromine and α-angelic lactone. Warming with sodium hydroxide converts the β-bromolævulinic acid into α-hydroxylævulinic acid and β-acetoacrylic acid. Ammonia converts the β-bromolævulinic acid into tetramethyl pyrazine, whilst aniline produces pyrazine-2,3-dimethyl indole (B. **21**, 3360).

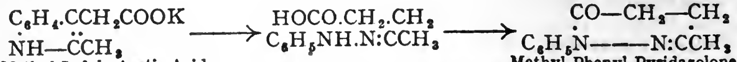
αβ-Dibromolævulinic Acid, $CH_3COCHBrCHBrCO_2H$, m.p. 108°, is prepared from β-acetacrylic acid and Br_2. *βδ-Dibromolævulinic Acid,* $CH_2BrCOCHBrCH_2CO_2H$, m.p. 115°, is produced in the bromination of lævulinic acid. It yields diacetyl and glyoxyl propionic acid, $HOC.CO.CH_2CH_2CO_2H$, when it is boiled with water. Concentrated nitric acid converts it into dibromodinitromethane and monobromosuccinic acid, whilst with concentrated sulphuric acid it yields two isomeric dibromo-diketo-R-pentenes (Vol. II.).

Nitrogen Derivatives of the γ-Ketonic Acids.

(1) *Lævulinamide,* $CH_3COCH_2CH_2CONH_2$ or $CH_3C(NH_2)CH_2CH_2COO$, m.p. 107° (see above).

(2) *Action of Hydrazine*, NH_2NH_2: *Lævulinic Hydrazide*, $CH_3COCH_2CH_2$-$CONHNH_2$, m.p. 82°. On the application of heat it passes into a lactazam (p. 406)—3-*Methyl Pyridazolone*, 3-*Methyl Pyridazinone*, $CH_3(C{=}N.NH)CH_2$-CH_2CO, m.p. 94° (B. **26**, 408; J. pr. Ch. [2] **50**, 522).

(3) *Action of Phenylhydrazine*, $NH_2NHC_6H_5$: The first product is a hydrazone, which yields a lactazam when heated. *Lævulinic Phenylhydrazone*, $CH_3C(=NNHC_6H_5)CH_2CH_2CO_2H$, m.p. 108°. This passes into 3-*Methyl Phenyl Pyridazolone*, m.p. 81° (A. **253**, 44). When fused with zinc chloride it becomes dimethylindol acetic acid,

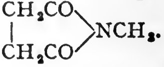


$$\begin{matrix} C_6H_4.CCH_2COOK \\ NH{-}CCH_3 \end{matrix} \longrightarrow \begin{matrix} HOCO.CH_2.CH_2 \\ C_6H_5NH.N{:}CCH_3 \end{matrix} \longrightarrow \begin{matrix} CO{-}CH_2{-}CH_2 \\ C_6H_5N{-}{-}{-}N{:}CCH_3 \end{matrix}$$

Methyl Indole Acetic Acid. Methyl Phenyl Pyridazolone.

Phenylhydrazone Mesitonic Acid, Phenylhydrazone α-Dimethyl Lævulinic Acid, $CH_3C(:NNHC_6H_5)CH_2C(CH_3)_2CO_2H$, m.p. 121·5°. It passes into 3-*Methyl* 1-*Dimethyl n-Phenyl Pyridazolone*, $C_6H_5NN{:}C(CH_3)CH_2C(CH_3)CO$, m.p. 84° (A. **247**, 105).

(4) *Action of Hydroxylamine*: *Lævulinic Oxime*, $CH_3C(NOH)CH_2CH_2CO_2H$, m.p. 95° (B. **25**, 1930), undergoes rearrangement in presence of concentrated sulphuric acid into succinyl methylimide,



$$\begin{matrix} CH_2CO \\ | \\ CH_2CO \end{matrix}\!\!>NCH_3.$$

IV. δ-Ketonic Acids.

Such acids have been prepared from acetyl glutaric acids (*q.v.*) by the cleavage of CO_2. On reduction they yield *d-lactones* (p. 375).

γ-Acetobutyric Acid, $CH_3CO.CH_2CH_2CH_2CO_2H$, m.p. 13°, b.p. 275°, is formed by the oxidation of γ-acetobutyl alcohol (p. 342); and from dihydroresorcinol by barium hydroxide solution. Sodium ethoxide changes it back into dihydroresorcinol.

γ-Ethyl γ-Acetobutyric Acid, $CH_3CO.CH(C_2H_5)CH_2CH_2CO_2H$, b.p._{10} 173°, b.p. 280°. *γγ-Dimethyl γ-Acetobutyric Acid*, $CH_3.COC(CH_3)_2CH_2CH_2COOH$, m.p. 48°, is obtained from αα-dimethyl glutaric ethyl ester acid chloride and zinc methyl (C. 1899, II. 524); also from isolauronolic acid and β-campholenic acid by oxidation (C. 1897, I. 26). *γ-Butyrobutyric Acid*, $CH_3CH_2CH_2CO.$-$CH_2CH_2CH_2CO_2H$, m.p. 34°, from coniine (Vol. II.) and H_2O_2.

Certain higher ketonic acids have been prepared by the oxidation of hydroaromatic compounds of the terpene group, and are important in determining the constitution of the latter. Other ketonic acids result from the hydrolysis of acetylene carboxylic acids by means of concentrated sulphuric acid. A case in point is *Ketostearic Acid*, from stearolic acid (p. 304), which is produced on treating oleic and elaïdic di-bromides with alcoholic potassium hydroxide. See oleic acid (p. 300) for the value of these ketonic acids in determining the constitution of the olefine and acetylene carbonic acids, which are closely related to them.

5-*Isopropyl-heptane*-2-*one Acid*, *β-Isopropyl δ-Acetyl Valeric Acid*, $CH_3CO.CH_2.$-$CH_2CH(C_3H_7)CH_2CO_2H$, m.p. 40°, b.p._{20} 192°, is prepared from tetrahydrocarvone, (Vol. II.). 2,6-*Dimethyl-octane*-3-*one Acid*, *β-Methyl δ-Isobutyl Valeric Acid*, $CH_3CH(CH_3)CO.CH_2CH_2CH(CH_3)CH_2CO_2H$, b.p._{20} 186°, is prepared from menthone (Vol. II.). *Undecanonic Acid*, $CH_3CO[CH_2]_8CO_2H$ (?), m.p. 49°, is formed from undecolic acid (p. 304).

8-*Ketostearic Acid*, $CH_3[CH_2]_8CO[CH_2]_7CO_2H$, m.p. 83°, is obtained from chloroketostearic acid (B. **29**, 806), and is a transposition product of ricinoleic acid (p. 302).

9-*Ketostearic Acid*, *Oxostearic acid*, $CH_3[CH_2]_7CO[CH_2]_8CO_2H$, m.p. 76°, is obtained from stearolic acid (p. 304) by the action of concentrated sulphuric acid; also by heating the salt of dihydroxystearic acid, produced by the oxidation of this acid by $KMnO_4$ (J. pr. Ch. [2] **71**, 422). Consult oleic acid (p. 300) for the decomposition of its oxime.

C. UNSATURATED KETONIC ACIDS. OLEFINE KETONIC ACIDS

β-Ketonic Acids:

Ethylidene Acetoacetic Ester, $CH_3CH:C<\begin{smallmatrix}COCH_3\\CO_2C_2H_5\end{smallmatrix}$, b.p. 211°, results from the action of hydrochloric acid, ammonia, diethylamine or piperidine on aldehyde and acetoacetic ester (A. **218,** 172; B. **29,** 172; **31,** 735). Magnesium methyl iodide converts it into a salt of isopropyl acetoacetic ester (C. 1902, I. 1197).

Isopropylidene Acetoacetic Ester, $(CH_3)_2C:C<\begin{smallmatrix}CO_2C_2H_5\\COCH_3\end{smallmatrix}$, b.p. 215°, is prepared from acetone and acetoacetic ester by the action of HCl and then of quinoline (B. **30,** 481).

Isoheptenoyl Acetic Acid, $(CH_3)_2C:CCH_2CH_2COCH_2CO_2H$, is prepared from isohexenyl propiolic acid (method of formation 7, p. 415); *ethyl ester,* b.p.$_{14}$ 127–130° (C. 1903, I. 1019).

γ-Ketonic Acids:

β-Acetoacrylic Acid, $CH_3CO.CH:CHCO_2H$, m.p. 125°, is derived together with β-hydroxylævulinic acid from β-bromolævulinic acid, and also from *chloral-acetone* upon digestion with a *soda* solution, It combines with HBr and with bromine, forming αβ-dibromolævulinic acid and α-bromolævulinic acid (A. **264,** 234). For constitution of β-acetoacrylic acid, see B. **35,** 1157.

β-Trichloracetoacrylic Acid, Trichlorophenomalic Acid, $CCl_3CO.CH:CHCO_2H$, or $CCl_3.\overbrace{C(OH)CH:CHCOO}$, m.p. 131°, is obtained from benzene by the action of potassium chlorate and sulphuric acid (A. **223,** 170; **239,** 176). It breaks up into chloroform and maleïc acid when boiled with barium hydroxide.

It yields *Acetyl Trichlorophenomalic Acid,* $CCl_3\overbrace{C(OCOCH_3)CH:CH.COO}$, m.p. 86° (A. **254,** 152), when treated with acetic anhydride. *Perchloracetyl Acrylic Acid,* $CCl_3COCCl:CCl.CO_2H$, m.p. 83–84° (B. **26,** 511), and other chlorinated acetyl acrylic and acetyl methyl acrylic acids (B. **26,** 1670), are formed from the decomposition of benzene derivatives which have previously been chlorinated.

β-Acetyl Dibromacrylic Acid, $CH_3CO.CBr:CBrCOOH$, or $CH_3.\overbrace{C(OH)CBr:CBr\text{-}COO}$, m.p. 78°, results upon treating α-tribromothiotolene with nitric acid. Its remarkably low conductivity points to a lactone formula (B. **24,** 77; **26,** R. 16).

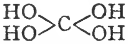
δ-Ketonic Acids.—Chlorinated δ-ketonic acids have been obtained from the ketochlorides of resorcinol and orcinol, *e.g.*, trichloracetyl trichlorocrotonic acid, $CCl_3CO.CCl:CHCCl_2CO_2H$ (B. **26,** 317, 504, 1666).

CARBONIC ACID AND ITS DERIVATIVES

The salts and esters of carbonic acid are derived from carbonic acid hydrate, $CO(OH)_2$, which is unstable in the free state, and which may be regarded also as hydroxyformic acid, HO.COOH. Its symmetrical structure distinguishes it, however, from the other hydroxy-acids containing three atoms of oxygen. It is a weak *dibasic* acid and constitutes the transition to the true dibasic dicarboxylic acids—hence it will be treated separately.

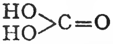
On attempting to liberate the hydrated acid from carbonates by a stronger acid, it breaks down, as almost always happens, when two hydroxyl groups are attached to the same carbon atom. A molecule of water separates, and carbon dioxide, CO_2, the anhydride of carbonic acid, is set free. The carbonates recall the sulphites in their behaviour, and carbon dioxide reminds us of sulphur dioxide or sulphurous anhydride.

Every carbon compound, containing an atom of carbon in double union with an oxygen atom, may be regarded as the anhydride of a dihydroxyl body corresponding with it. The hydrate formula, $C{=}O(OH)_2$, of carbonic acid may be viewed as the formula of an anhydride of the compound $C(OH)_4$. Of course a compound of this form will be as unstable as orthoformic acid, $HC(OH)_3$ (p. 235). However, esters derived from the formula $C(OH)_4$, can actually be prepared; they are the *orthocarbonic esters*. In a broader sense, all methane derivatives, in which the four hydrogen atoms have been replaced by four univalent elements or residues, must be considered as derivatives of orthocarbonic acid, *e.g.* tetrachloro-, tetrabromo-, tetra-iodo-, and tetrafluoro-methane. From this point of view tetrachloromethane is the chloride of orthocarbonic acid. These compounds, together with chloropicrin, CCl_3NO_2, bromopicrin, CBr_3NO_2, bromonitroform, $CBr(NO_2)_3$, and tetranitromethane, $C(NO_2)_4$, will be discussed later as derivatives of orthocarbonic acid. The carbon tetramide is not known. Ammonia appears most frequently in the reactions where it might well be expected, and also guanidine, which sustains the same relation to the hypothetical carbon tetramide—the amide of orthocarbonic acid, as metacarbonic acid bears to the ortho-acid:



$$\begin{matrix}HO\\HO\end{matrix}{>}C{<}\begin{matrix}OH\\OH\end{matrix}$$

Orthocarbonic Acid,
(does not exist).

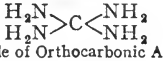


$$\begin{matrix}HO\\HO\end{matrix}{>}C{=}O$$

Metacarbonic Acid,
(does not exist).

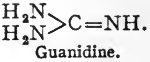
$$O{=}C{=}O$$

Carbon Dioxide,
Carbonic Acid Anhydride.



$$\begin{matrix}H_2N\\H_2N\end{matrix}{>}C{<}\begin{matrix}NH_2\\NH_2\end{matrix}$$

Amide of Orthocarbonic Acid
(does not exist).



$$\begin{matrix}H_2N\\H_2N\end{matrix}{>}C{=}NH.$$

Guanidine.

Carbon Monoxide, CO, the first oxidation product of carbon, was described immediately after formic acid (p. 247). When carbon is oxidized, the temperature determines whether carbon monoxide or dioxide shall be formed: at a high temperature only the monoxide is formed, the carbon behaving as a di-valent element.

Carbon Dioxide, CO_2, is the final combustion product of carbon. Under favourable conditions the carbon of every organic substance will be converted into it. In the quantitative analysis of carbon derivatives carbon is determined in the form of CO_2 (p. 3).

Liquid carbon dioxide is a good solvent for many organic substances, especially those that are more volatile, a behaviour which resembles the organic solvents (C. 1906, I. 1239).

Several of the methods for the formation of carbon dioxide, which are especially important in organic chemistry, may be mentioned here. Carbon dioxide is developed from fermentable sugars in the alcoholic fermentation process (p. 112). It is readily formed by the oxidation of formic acid (p. 238), into which it can be converted by reduction (B. 28, R. 458); and can be withdrawn from the carboxylic acids, *i.e.* from the acids containing carboxyl, $-C{\lessgtr}\begin{matrix}OH\\O\end{matrix}$, when hydrogen will enter where the carboxyl group was first attached. Those polycarboxylic acids, containing two carboxyl groups in union with each other, or two and more carboxyls linked to the same carbon atom, readily part with carbon dioxide on the application of heat. In the latter case carboxylic acids result, in which each carboxyl remaining over is attached to a particular carbon atom, *e.g.*:

$$\text{Malonic Acid, } HO_2C.CH_2.CO_2H \longrightarrow CO_2+CH_3.CO_2H.$$

The β-ketonic acids behave similarly (p. 410), *e.g.*:

$$\text{Acetoacetic Acid, } CH_3COCH_2.CO_2H \longrightarrow CO_2 \text{ and } CH_3CO.CH_3.$$

Monocarboxylic acids or their alkali salts can be deprived of CO_2 upon heating them with NaOH, when it is withdrawn as Na_2CO_3 (p. 72):

$$CH_3CO_2Na+NaOH=Na_2CO_3+CH_4.$$

The electric current, acting on concentrated solutions of the alkali salts of carboxylic acids, splits off carbon dioxide (p. 71), *e.g.*:

$$2CH_3CO_2K \longrightarrow \overbrace{CH_3CH_3+2CO_2}^{+} \text{ and } 2K.$$

The calcium salts of many carboxylic acids are decomposed by heat with the production of calcium carbonate and ketones (p. 190), *e.g.*:

$$(CH_3CO_2)_2Ca \longrightarrow CaCO_3+CH_3COCH_3.$$

These and similar reactions, in which CO_2 readily separates from organic compounds, are of the first importance in the production of the different classes of compounds. In contrast to the splitting-off of CO_2 in certain reactions we have its absorption by certain organic metallic derivatives: nucleus-syntheses, in which carboxylic acids are produced:

$$CH_3MgI+CO_2=CH_3CO_2MgI\,;\; CH_3C{\equiv}CNa+CO_2=CH_3C{\equiv}CCO_2Na\,;$$

$$C_6H_5ONa+CO_2=C_6H_4{<}{}^{CO_2Na}_{OH} \text{ (comp. \textit{Salicylic Acid}, Vol. II.).}$$

Esters of Metacarbonic Acid, or ordinary Carbonic Acid.

The **primary esters** of carbonic acid are not stable in a free condition. They are prepared from the alcohols and carbon dioxide at low temperatures (B. **31**, 3001).

Dumas and *Peligot* obtained the barium salt of methyl carbonic acid on conducting carbon dioxide into a methyl alcohol solution of anhydrous barium hydroxide (A. **35**, 283).

Magnesium methoxide combines with CO_2 to form magnesium methyl carbonate (B. **30**, 1836).

The potassium salt of **Ethyl Carbonic Acid**, $CO{<}{}^{O.C_2H_5}_{OK}$, separates in pearly scales on adding CO_2 to the alcoholic solution of potassium alcoholate. Water decomposes it into potassium carbonate and alcohol.

The **neutral esters** appear (1) when the alkyl iodides act on silver carbonate:

$$Ag_2CO_3+2C_2H_5I=(C_2H_5)_2CO_3+2AgI\,;$$

also (2) by treating esters of chloroformic acid with alcohols, whereby **mixed esters** may also be obtained:

$$CH_3OCOCl+HOC_2H_5=\underset{\text{Methyl Ethyl Carbonate.}}{CH_3OCO.OC_2H_5}+HCl.$$

This shows that, with application of heat, the higher alcohols are able to expel the lower alcohols from the mixed esters:

$$\underset{\text{Methyl Ethyl Ester.}}{C_2H_5OCOOCH_3}+C_2H_5.OH=\underset{\text{Diethyl Ester.}}{C_2H_5OCOOC_2H_5}+CH_3OH.$$

Hence, to obtain the mixed ester, the reaction must occur at a lower temperature.

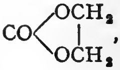
As regards the nature of the product, it is immaterial as to what order is pursued in introducing the alkyl groups, *i.e.* whether proceeding from chloroformic ester, we let ethyl alcohol act on it, or reverse the case, letting methyl alcohol act on ethyl chloroformic ester; the same methyl ethyl carbonic acid results in each case (B. **13**, 2417). This is an additional confirmation of the like valence of the carbon affinities, already proved by numerous experiments made with that direct object (with the mixed ketones) in view (p. 22) (C. 1901, II. 219).

The neutral carbonic esters are ethereal smelling liquids, dissolving readily in water. Excepting the dimethyl and the methyl ethyl ester, all are lighter than water. With ammonia they first yield carbamic esters and then urea. When they are heated with phosphorus pentachloride, an alkyl group is eliminated, and in the case of the mixed esters this is always the lower one, whilst the chloroformic esters constitute the product:

$$C_2H_5OCOOCH_3+PCl_5=C_2H_5OCOCl=POCl_3+CH_3Cl.$$

Carbonic esters are converted to carboxylic esters by alkyl and aryl-magnesium halides (B. **38**, 561).

Methyl Carbonic Ester, $CO(OCH_3)_2$, b.p. 91°, is produced from chloroformic ester by heating it with lead oxide; *methyl ethyl ester*, $CH_3OCOOC_2H_5$, b.p. 109°; *diethyl ester*, $CO(OC_2H_5)_2$, b.p. 126°, is obtained from ethyl oxalate, on warming with sodium or sodium ethoxide (with evolution of CO); *methyl propyl ester*, b.p. 131°.

Glycol Carbonate, Carbonic Ethylene Ester,  $CO\begin{matrix}OCH_2\\ | \\ OCH_2\end{matrix}$, m.p. 39°, b.p. 236°, is obtained from glycol and $COCl_2$.

Derivatives of Orthocarbonic Acid (p. 426).

Orthocarbonic Ester or *Tetrabasic Carbonic Ester* (*Bassett*, 1864, A. **132**, 54), is produced when sodium alcoholates act on chloropicrin:

$$CCl_3(NO_2)+4C_2H_5ONa=C(OC_2H_5)_4+3NaCl+NaNO_2.$$

Orthocarbonic Ethyl Ester, $C(OC_2H_5)_4$, b.p. 158°, is a liquid with an ethereal odour. When heated with ammonia it yields guanidine (p. 455) and alcohol. Alkyl and aryl magnesium halides convert it to ortho-carboxylic esters, $RC(CC_2H_5)_3$ (p. 284) (B. **38**, 563).

The *propyl ester*, $C(OC_3H_7)_4$, b.p. 224°; *isobutyl ester*, b.p. 245°; *methyl ester* apparently can not be prepared (A. **205**, 254).

The tetrahalogen substitution products of methane appear to be the halides corresponding with orthocarbonic acid. They bear the same relation to the orthocarbonic esters that chloroform, bromoform and iodoform sustain to the orthoformic esters. Indeed, tetrachloro- and tetrabromomethane and sodium alcoholate do yield orthocarbonic esters, though with poor yield (B. **38**, 563; C. 1906, I. 1691). The formation of orthocarbonic acid and trichloromethyl sulphochloride (p. 434) by means of $NaOC_2H_5$, see C. 1908, I. 1041.

Methane Tetrahalogen Substitution Products:

Tetrafluoromethane, Carbon Tetrafluoride, CF_4, is a colourless gas, condensable by pressure. It is remarkable that this body belongs to that small class of carbon derivatives which can be directly prepared from the elements. Finely divided carbon, *e.g.* lamp black, combines directly with fluorine, with production of light and heat.

Tetrachloromethane or Carbon Tetrachloride, CCl_4, solidifies —30°, b.p. 76°, D_0=1·631, is formed (1) by the action of chlorine on chloroform in sunlight, or upon the addition of iodine, and (2) by action of Cl on CS_2 at 20–40°, C_2Cl_4 and C_2Cl_6 being formed at the same time (B. **27,** 3160); (3) upon heating CS_2 with S_2Cl_2 in the presence of small quantities of iron: $CS_2+2S_2Cl_2=CCl_4+6S$ (D. R. P. 72999). Preparation of the pure substance, see C. 1899, II. 1098.

It is a pleasant-smelling liquid solidifying to a crystalline mass at —30°. It is an excellent solvent for many substances, and is made upon a technical scale. When heated with alcoholic KOH, it decomposes according to the following equation:

$$CCl_4+6KOH=K_2CO_3+3H_2O+4KCl.$$

When the vapours are conducted through a red-hot tube, decomposition occurs, and C_2Cl_4 and C_2Cl_6 are produced. This is an interesting reaction because, as we have learned under acetic acid (p. 288), it plays a part in the first synthesis of this long-known acid. C_2Cl_6 is produced from CCl_4 by means of aluminium amalgam (p. 96). When carbon tetrachloride is digested with phenols and sodium hydroxide, *phenol carboxylic acids* are produced (Vol. II.).

Tetrabromomethane, CBr_4, m.p. 92·5°, b.p. 189°, obtained by the action of brom-iodide on bromoform or CS_2, or of bromine and alkali on acetone and other compounds (C. 1906, I. 1691), crystallizes in shining plates.

Tetraiodomethane, CI_4, D_{20}=4·32, is formed when CCl_4 is heated with aluminium iodide. It crystallizes from ether in dark-red, regular octahedra. On exposure to air it decomposes into CO_2 and I, a change which is accelerated by heat.

Nitro-derivatives of Orthocarbonic Acid.

Nitrochloroform, *Chloropicrin,* $C(NO_2)Cl_3$, b.p. 112°, D_0=1·692, is frequently produced in the action of nitric acid on chlorinated carbon compounds such as chloral, and also when chlorine or bleaching powder acts on nitro-derivatives, picric acid and nitromethane; also from mercury fulminate (p. 249).

In the preparation of chloropicrin, 10 parts of bleaching powder are mixed to a thick paste with water. To this is added 1 part of picric acid or [2,4,6]-trinitrophenol, $C_6H_2[1]OH[2,4,6,](NO_2)_3$.

Chloropicrin is a colourless liquid, possessing a very penetrating odour that attacks the eyes powerfully. It explodes when heated rapidly. When treated with acetic acid and iron filings it is converted into methylamine:

$$CCl_3(NO_2)+6H_2=CH_3.NH_2+3HCl+2H_2O.$$

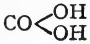
Alkali sulphites change it to formyl trisulphonic acid, ammonia to guanidine, and sodium ethoxide to orthocarbonic ester (p. 428).

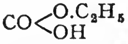
Bromopicrin, $CBr_3(NO_2)$, m.p. 10°, can be distilled under greatly reduced pressure without decomposition, and is formed, like the preceding chloro-compound, by heating picric acid with calcium hypobromite (calcium hydroxide and bromine), or by heating nitromethane with bromine (p. 151). It closely resembles chloropicrin.

Bromonitroform, tetranitromethane and the salts of the nitroforms, which belong here, have already been described among the nitro-paraffins (p. 155, see also p. 339).

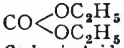
CHLORIDES OF CARBONIC ACID

Two series of salts, two series of esters, and two chlorides can be obtained theoretically from a dibasic acid:

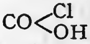

$CO{<}^{OH}_{OH}$


$CO{<}^{O.C_2H_5}_{OH}$

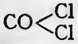
Ethyl Carbonic Acid, only known as salt.


$CO{<}^{OC_2H_5}_{OC_2H_5}$

Carbonic Acid, Diethyl Ester.


$CO{<}^{Cl}_{OH}$

Chlorocarbonic Ester, only known as ester.


$CO{<}^{Cl}_{Cl}$

Phosgene.

(1) **Chlorocarbonic Ester.**—The primary chloride of carbonic acid, *chlorocarbonic acid*, is not known, because it loses HCl too easily. Its esters are, however, known, and are produced when alcohols act on phosgene or carbon oxychloride, the secondary chloride of carbonic acid (*Dumas*, 1833). They are often called chloroformic esters, because they can be regarded as esters of the chlorine substitution products of formic acid:

$$COCl_2+C_2H_5OH=ClCOOC_2H_5+HCl.$$

They are most readily prepared by introducing the alcohol into liquid and strongly cooled phosgene (B. **18**, 1177). They are volatile, disagreeable-smelling liquids, decomposable by water, and when heated with anhydrous alcohols they yield the neutral carbonic esters; with ammonia they yield urethanes (p. 435); with hydrazine, hydrazicarbonic esters (p. 446); with ammonium hydrazide, nitrogen compounds of carbonic esters (see below). They contain the group COCl, just as in acetyl chloride; hence they behave like fatty acid chlorides.

The *methyl ester*, $Cl.CO_2CH_3$, b.p. 71·4°; *ethyl ester*, b.p. 93°; $D_{15}=1·14396$; *propyl ester*, b.p. 115°; *isobutyl ester*, b.p. 128·8°; *isoamyl ester*, b.p. 154° (B. **13**, 2417; **25**, 1449); *allyl ester*, b.p. 180° (A. **302**, 262).

Perchlorocarbonic Ethyl Ester, $Cl.COOC_2Cl_5$, m.p. 26°, b.p. 83°, b.p.$_{760}$ 209°, D=1·737, is isomeric with perchloracetic methyl ester (p. 288; A. **273**, 56).

Chlorocarbonate of Glycollic Ester, $Cl.CO.OCH_2CO_2C_2H_5$, b.p. 182°. *Chlorocarbonate of Lactic Ester*, $CH_3CH(OCOCl).CO_2C_2H_5$, b.p.$_{19}$ 91° (A. **302**, 262).

(2) **Carbonyl Chloride**, *Phosgene Gas, Carbon Oxychloride*, $COCl_2$, b.p. 8°, was first obtained by *Davy*, in 1812, by the direct union of CO with Cl_2 in sunlight; hence the name phosgene, from φῶς, light, and γεννάω, to produce. It is also formed by conducting CO into boiling $SbCl_5$, and by oxidizing chloroform by air in the sunlight or with chromic acid:

$$2CHCl_3+CrO_3+2O=2COCl_2+H_2O+CrO_2Cl_2.$$

Phosgene is most conveniently prepared from carbon tetrachloride (100 c.c.), and 80 per cent. "Oleum" (120 c.c.), a sulphuric acid containing SO_3 (B. **26**, 1990), when the SO_3 is converted into pyrosulphuryl chloride, $S_2O_5Cl_2$.

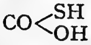
Technically it is made by conducting CO and Cl_2 over pulverized and cooled bone charcoal (*Paternò*).

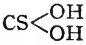
Carbonyl chloride is a colourless gas, which on cooling is condensed to a liquid. *Reactions:* (1) Water at once breaks it up into CO_2 and 2HCl. (2) Alcohols convert it into chlorocarbonic and carbonic esters. (3) With ammonium chloride it forms *urea chloride*. (4) Urea is produced when ammonia acts on it. Phosgene has been employed in numerous nucleus-synthetic reactions, *e.g.* it has been used technically for the preparation of di- and tri-phenylmethane dyestuffs (see Tetramethyl Diamidobenzophenone, Vol. II.).

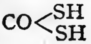
Carbonyl Bromide, $COBr_2$, b.p. 64–65°, $D_{15}=2{\cdot}45$, is prepared from carbon tetrabromide and concentrated sulphuric acid, at 150–160°. It is a colourless liquid which fumes in the air (A. **345**, 334).

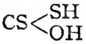
SULPHUR DERIVATIVES OF ORDINARY CARBONIC ACID

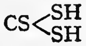
By supposing the oxygen in the formula $CO(OH)_2$ to be replaced by sulphur, there result:

1.  $CO<\begin{matrix}SH\\OH\end{matrix}$ *Thiocarbonic Acid* Carbonmonothiolic Acid.

2.  $CS<\begin{matrix}OH\\OH\end{matrix}$ *Sulphocarbonic Acid* Thion-carbonic Acid.

3.  $CO<\begin{matrix}SH\\SH\end{matrix}$ *Dithiocarbonic Acid* Carbondithiolic Acid

4.  $CS<\begin{matrix}SH\\OH\end{matrix}$ *Sulphothiocarbonic Acid* Thion-carbon-thiolic Acid.

5.  $CS<\begin{matrix}SH\\SH\end{matrix}$ *Trithiocarbonic Acid.*

The doubly-linked *S* is indicated in the name by *sulph* or *thion*, whilst it is termed *thio* or *thiol* when singly linked.

The free acids are not known, or are very unstable, but numerous derivatives, such as salts, esters and amides, are known. *Carbon oxysulphide*, COS, is the anhydride or sulphanhydride corresponding with thiocarbonic acid, sulphocarbonic acid and dithiocarbonic acid. *Carbon Disulphide*, CS_2, sustains the same relation to sulphothiocarbonic acid and trithiocarbonic acid that carbon dioxide does to ordinary carbonic acid.

Phosgene corresponds with thiophosgene, $CSCl_2$.

The two anhydrides, COS and CS_2, will first be discussed, then the salts and esters of the five acids just mentioned, to which thiophosgene and the sulphur derivatives of the chlorocarbonic esters are connected.

Carbon Oxysulphide, COS (1867 *C. v. Than*, A. Spl. **5**, 245), occurs in some mineral springs as, for example, in the sulphur waters of Harkány and Parád in Hungary, and is formed (1) by conducting sulphur vapour and carbon monoxide through red-hot tubes; (2) on heating CS_2 with SO_3; (3) by the action of $COCl_2$ on CdS at 260–280° (B. **24**, 2971); (4) by the action of fatty acids (p. 276); or (5) sulphuric acid, diluted with an equal volume of water on potassium thiocyanate, $HSNC+H_2O=COS+NH_3$ (B. **20**, 550).

In order to obtain it pure (B. **36**, 1008) the gas may be conducted into an alcoholic potassium hydroxide solution, and (6) the separated potassium ethyl thiocarbonate, C_2H_5OCOSK, decomposed with dilute hydrochloric acid.

Carbon oxysulphide is a colourless gas, with a faint and peculiar odour. It inflames readily, and forms an explosive mixture with air. It is soluble in an equal volume of water, and in 6 volumes of toluene at 14°. It is decomposed by the alkalis according to the following equation:

$$COS+4KOH=K_2CO_3+K_2S+2H_2O.$$

Carbon Disulphide, CS_2, b.p. 47°, D_0 1·297, was first obtained in 1796 by *Lampadius*, when he distilled pyrites with carbon. It is prepared by conducting sulphur vapour over ignited charcoal, and is one of the few carbon compounds which can be prepared by the direct union of carbon with other elements. It is a colourless liquid with strong refractive power. It is obtained pure by distilling the commercial product over mercury or mercuric chloride; its odour is then very faint. It is almost insoluble in water, but mixes with alcohol and ether. It serves as an excellent solvent for iodine, sulphur, phosphorus, fatty oils and resins, and is used in the vulcanization of rubber. In the cold it combines with water, yielding the *hydrate* $2CS_2+H_2O$, which decomposes again at —3°.

Small quantities of carbon disulphide are detected by conversion into *potassium xanthate*, by means of alcoholic potassium hydroxide, from which the copper salt is obtained. The production of the bright-red compound of CS_2 with triethyl phosphine (p. 173, and B. **13**, 1732) is a more delicate test. Comp. also the mustard-oil reaction, p. 63.

H_2S and CS_2 conducted over heated copper yield methane (p. 71). Carbon disulphide is fairly stable towards dry halogens, so that it is frequently used as a solvent in adding halogens to unsaturated carbon compounds.

However, moist chlorine gas converts CS_2 into thiocarbonyl chloride, $CSCl_2$, and in the presence of iodine into CCl_3SCl, *perchloromethyl mercaptan* and S_2Cl_2; finally into CCl_4 (p. 429). Alcoholates change it into *xanthates*.

Thiocarbonic Acids.—The salts and esters of all these acids, which when free are exceedingly unstable, may be produced (1) by the union of the anhydrides, CO_2, COS, CS_2, with (*a*) the sulphides of the alkali and alkali earth metals, (*b*) the mercaptides of the alkali metals, (*c*) and of the last two with alcoholates; (2) by the transposition of the salts thus obtained with alkylogens and alkylene dihalides; (3) by the action of alcohols and alcoholates, mercaptans and alkali mercaptides on $COCl_2$, $Cl.CO_2C_2H_5$ (p. 430), $CSCl_2$ and $Cl.CS_2C_2H_5$ (p. 434).

Monothiocarbonic Acids.

1. **Ethyl Thiocarbonic Acid**, *Ethyl Carbon-monothiolic Acid*, $HS.CO.OC_2H_5$. The *potassium salt* (*Bender's salt*), $KS.COOC_2H_5$, is obtained (1) from ethyl xanthic esters and alcoholic potassium hydroxide (p. 433), and (2) from carbon oxysulphide and alcoholic potassium hydroxide (J. pr. Ch. [2] **73**, 242). It forms prisms, easily soluble in water and alcohol, and produces a white precipitate with copper sulphate. With ethyl iodide its salt forms *Thio-ethyl Carbonic Ethyl Ester*, $C_2H_5S.COOC_2H_5$, b.p. 156°, which can also be prepared from chlorocarbonic ester, $ClCOOC_2H_5$, and sodium or zinc mercaptide. Alkalis decompose it into carbonate, alcohol and mercaptan (B. **19**, 1227). *Thiodicarbonic Ester*, $S(COOC_2H_5)_2$, b.p.$_{22}$ 118°, is produced from chlorocarbonic ester and Na_2S (J. pr. Ch. [2] **71**, 278).

2. **Sulphocarbonic Acid**, *Thion-carbonic Acid*, HOCSOH. Its *ethyl ester*, $CS(O.C_2H_5)_2$, b.p. 161°, is produced by the action of sodium alcoholate on thiocarbonyl chloride, $CSCl_2$, and in the distillation of $S_2(CSOC_2H_5)$. It is an ethereal smelling liquid. With alcoholic ammonia the ester decomposes into alcohol and ammonium thiocyanate, $CN.S.NH_4$.

Dithiocarbonic Acids.

3. **Dithiocarbonic Acid**, *Carbon-dithiolic Acid*, $CO(SH)_2$. The free acid is not known.

The *methyl ester*, $CO(S.CH_3)_2$, b.p. 169°; *ethyl ester*, $CO(S.C_2H_5)_2$, b.p. 196°. These result (1) when $COCl_2$ acts on the mercaptides:

$$COCl_2+2C_2H_5.SK=CO(S.C_2H_5)_2+2KCl;$$

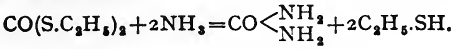
and (2) when thiocyanic esters (p. 468) are heated with concentrated sulphuric acid:

$$2CN.S.CH_3+3H_2O=CO(S.CH_3)_2+CO_2+2NH_3.$$

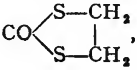
(3) from imido-dithio-carbonic ester (p. 450) and dilute hydrochloric acid (C. 1905, I. 447):

$$RN{:}C(SCH_3)_2 + H_2O = OC(SCH_3)_2 + RNH_2.$$

They are liquids with an odour of garlic. Alcoholic ammonia decomposes them into urea and mercaptans:



$$CO(S.C_2H_5)_2 + 2NH_3 = CO\begin{smallmatrix}NH_2\\NH_2\end{smallmatrix} + 2C_2H_5.SH.$$

Dithiocarbonic Ethylene Ester, CO, m.p. 310°, is produced from trithiocarbonic ethylene ester.

4. **Sulphothiocarbonic Acid**, *Thion-carbon-thiolic Acid*, HO.CS.SH, does not exist free. The *xanthates*, R.O.C.SSMe, discovered by *Zeise* in 1824, are obtained from it.

The **xanthates** are produced by the interaction of CS_2 and alkali hydroxides in alcoholic solution—*e.g.* potassium xanthate, consisting of yellow, silky needles, which crystallize:

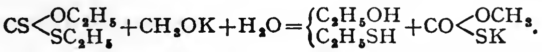
$$CS_2 + KOH + C_2H_5.OH = \underset{\text{Potassium Ethyl Xanthate.}}{C_2H_5OCSSK} + H_2O.$$

Cupric salts precipitate *yellow* copper salts from solutions of the alkali xanthates together with disulphides $S_2(CSOR)_2$ (comp. B. **38**, 2184; C. 1908, I. 1092). The acid owes its name, ξανθός, yellow, to this characteristic. By the action of alkyl iodides on the salts the esters are formed.

The latter are liquids possessing an odour of garlic, and are not soluble in water. Ammonia decomposes them into mercaptans and esters of sulphocarbamic acid (p. 448):

$$C_2H_5OCS.SC_2H_5 + NH_3 = C_2H_5OCS.NH_2 + C_2H_5SH.$$

Alkali alcoholates cause the production of mercaptan and alcohol, and salts of the alkyl thiocarbonic acids (p. 432) (B. **13**, 530):



$$CS\begin{smallmatrix}OC_2H_5\\SC_2H_5\end{smallmatrix} + CH_3OK + H_2O = \begin{cases}C_2H_5OH\\C_2H_5SH\end{cases} + CO\begin{smallmatrix}OCH_3\\SK\end{smallmatrix}.$$

Ethyl Xanthic Acid, C_2H_5OCSSH, is a heavy liquid, not soluble in water. It decomposes at 25° into alcohol and CS_2.

Sulphocarboxethyl Disulphide, $(S.CS.O.C_2H_5)_2$, m.p. 28°, is produced on dding a solution of iodine or copper salts to potassium xanthate (see above, nd p. 274, for the formation of acetyl disulphide and the disulphides from the arbithionic acids).

Ethyl Xanthate Ethyl Ester, $C_2H_5.O.CS.S.C_2H_5$, b.p. 200°, is a colourless oil.

Methyl Xanthic Ethyl Ester, $CH_3OCSSC_2H_5$ (C. 1906, II. 502), b.p. 184°, and *thyl Xanthic Methyl Ester*, $C_2H_5.O.CS.S.CH_3$, b.p. 184°, are distinguished by heir behaviour towards ammonia and sodium alcoholate (see above).

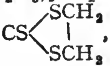
Ethylene Xanthic Ester, $C_2H_4(SCSOC_2H_5)_2$, is decomposed by alkalis into the yclic trithiocarbonic ethylene ester (p. 434) and *Bender's* salt (p. 432) (B. **38**, 88). *Ethyl Xanthic Formic Ester*, $C_2H_5OCS(SCOOC_2H_5)$, b.p. 133°, and *Ethyl anthic Acetic Acid*, $C_2H_5OCS(SCH_2COOH)$, m.p. 58°, are formed from a xanthate nd chloroformic ester and chloroacetic ester respectively (J. pr. Ch. [2] **71**, 264).

5. **Trithiocarbonic Acid**, $CS(SH)_2$, is precipitated by hydrochloric acid as reddish-brown, oily liquid, from solutions of its alkali salts, which are the roducts of interaction between carbon disulphide and alkali sulphide. It is nsoluble in water and is very unstable. CS_2 and alkaline solutions of copper orm well crystallizable double salts, CS_3CuK, $CS_3Cu(NH_4)$ (B. **35**, 1146). Other lts, such as $CS_3.Ba$, see C. 1907, I. 539; J. pr. Ch. [2] **73**, 245.

The alkali salts of the trithiocarbonic acids, reacting with the corresponding halogen compound, give rise to the following esters:

Trithiocarbonic Methyl Ester, $CS(SCH_3)_2$, b.p. 204–205°.

Trithiocarbonic Ethyl Ester, $CS(SC_2H_5)_2$, b.p. 240°, with decomposition.

Trithiocarbonic Ethylene Ester,  $CS\begin{cases}SCH_2\\ \mid\\ SCH_2\end{cases}$, m.p. 39·5°, is converted by oxidation with dilute nitric acid into *Dithiocarbonic Ethylene Ester* (p. 433) (A. **126**, 269).

Trithiocarboxylic Diglycollic Acid, $SC(SCH_2COOH)_2$, m.p. 172°, is formed from potassium trithiocarbonate and chloracetic acid. Oxidation converts it into *Carbonyl Dithioacetic Acid*, $OC(SCH_2COOH)_2$, m.p. 156° (J. pr. Ch. [2] **71**, 287).

Chlorides of the Sulphocarbonic Acids: *Thiophosgene, Thiocarbonyl Chloride*, $CSCl_2$, b.p. 73°, D=1·508, is produced when chlorine acts on carbon disulphide, and when the latter is heated with PCl_5 in closed tubes to 200°:

$$CS_2+PCl_5=CSCl_2+PCl_3S.$$

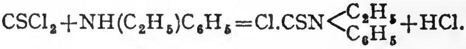
It is most readily obtained by reducing perchloromethyl mercaptan, $CSCl_4$ (below), with stannous chloride, or tin and hydrochloric acid (B. **20**, 2380; **21**, 102):

$$CSCl_4+SnCl_2=CSCl_2+SnCl_4.$$

This is the method employed for its production in large quantities.

It is a pungent, red-coloured liquid, insoluble in water. On standing exposed to sunlight it is converted into a polymeric, crystalline compound, $C_2S_2Cl_4$ $=Cl.CS.S.CCl_3$, *methyl perchlorodithioformate*, m.p. 116°, which at 180° reverts to the liquid body (B. **26**, R. 600). Water decomposes thiophosgene into CO_2 H_2S and 2HCl, whilst ammonia converts it into ammonium thiocyanate (p. 467).

Thiocarbonyl chloride converts secondary amines (1 molecule) into dialkyl sulphocarbamic chlorides:



$$CSCl_2+NH(C_2H_5)C_6H_5=Cl.CSN\begin{matrix}<\end{matrix}\begin{matrix}C_2H_5\\C_6H_5\end{matrix}+HCl.$$

A second molecule of the amine produces tetra-alkylic thioureas (B. **21**, 102).

Phosgene and thiophosgene, when acted on by alcohols and mercaptans, yield *sulphur derivatives of chlorocarbonic ester*.

Chlorocarbon-thiolic Ethyl Ester	$Cl.COSC_2H_5$
Chlorothioncarbonic Ethyl Ester	$Cl.CSOC_2H_5$
Chlorodithiocarbonic Ethyl Ester	$Cl.CSSC_2H_5$, b.p.$_{10}$ 90° (B. **36**, 3377)
Perchlorodithiocarbonic Methyl Ester . .	$Cl.CSSCCl_3$ (see above, thiophosgene)

SULPHUR DERIVATIVES OF ORTHOCARBONIC ACID

Perchloromethyl Mercaptan, $CCl_3.SCl$, b.p. 147°, results from the action of chlorine on CS_2. It is a bright yellow liquid. Stannous chloride reduces it to thiophosgene. Nitric acid oxidizes it to

Trichloromethyl Sulphonic Chloride, $CCl_3.SO_2Cl$, m.p. 135°, b.p. 170°, which can also be made by the action of moist chlorine on CS_2. It is insoluble in water, but dissolves readily in alcohol and ether. Its odour is like that of camphor, and excites tears. Water changes the chloride to

Trichloromethyl Sulphonic Acid, $CCl_3.SO_3H+H_2O$, consisting of deliquescent crystals. By reduction it yields $CHCl_2.SO_3H$, dichloromethyl sulphonic acid, $CH_2Cl.SO_3H$, monochloromethyl sulphonic acid, and $CH_3.SO_3H$ (p. 146).

Dibromomethane Diethyl Sulphone, $CBr_2(SO_2C_2H_5)_2$, m.p. 131°, and *diethyl sulphone diiodomethane*, $CI_2(SO_2C_2H_5)_2$, m.p. 176°, are formed when bromin acts on the potassium salt of methane, diethylsulphone, and iodine i potassium iodide, or iodine alone (B. **30**, 487).

Potassium Di-iodomethane Disulphonate, $CI_2(SO_3K)_2$, and *Potassium Iodomethane Disulphonate*, $CHI(SO_3K)_2$, are produced when potassium diazomethan disulphonate is decomposed with iodine and with hydrogen iodide. Sodiun amalgam reduces both bodies to methylene disulphonic acid (p. 210).

Potassium Methanol Trisulphonate, $HO.C(SO_3K)_3.H_2O$, results when th addition product of acid potassium sulphite and potassium diazomethane disulphonate is boiled with hydrochloric acid. A similar treatment of potassium sulph-hydrazimethylene trisulphonate will also yield it (B. **29**, 2161).

AMIDE DERIVATIVES OF CARBONIC ACID

Carbonic acid forms amides which are perfectly analogous to those of a dibasic acid—*e.g.* oxalic acid (p. 480):

$CO{<}\genfrac{}{}{0pt}{}{NH_2}{OH}$

Carbamic Acid.

$CO{<}\genfrac{}{}{0pt}{}{NH_2}{OC_2H_5}$

Urethane, Carbamic Ester.

$CO{<}\genfrac{}{}{0pt}{}{NH_2}{Cl}$

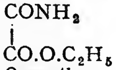
Urea Chloride, Carbamic Chloride.

$CO{<}\genfrac{}{}{0pt}{}{NH_2}{NH_2}$

Urea, Carbamide.

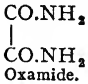
$\begin{array}{l}CONH_2\\|\\COOH\end{array}$

Oxamic Acid.



$\begin{array}{l}CONH_2\\|\\CO.O.C_2H_5\end{array}$

Oxamethane, Oxamic Ester.



$\begin{array}{l}CO.NH_2\\|\\CO.NH_2\end{array}$

Oxamide.

Carbamic Acid, *Amidoformic Acid,* $H_2N.COOH$, is not known in a free state. Its ammonium salt is contained in commercial ammonium carbonate, when this is prepared by the direct union of two molecules of ammonia with one of carbon dioxide. It is a white mass which breaks up at 60° into $2NH_3$ and CO_2, which combine again upon cooling. By the absorption of water it changes into ammonium carbonate. When ammonium carbamate is heated to 130–140° in sealed tubes, water is withdrawn and urea, $CO(NH_2)_2$, formed. For other *salts* of carbamic acid, see J. pr. Ch. [2] **16,** 180.

The *esters* of carbamic acid are called **urethanes**; these are obtained (1) by the action of ammonia at ordinary temperatures on carbonic esters:

$$C_2H_5O.CO.OC_2H_5+NH_3=C_2H_5O.CO.NH_2+C_2H_5OH;$$

and (2) in the same manner from the esters of chlorocarbonic and cyanocarbonic acids:

$$C_2H_5OCO.Cl+2NH_3=C_2H_5OCO.NH_2+NH_4Cl,$$
$$C_2H_5OCO.CN+2NH_3=C_2H_5OCO.NH_2+CN.NH_4.$$

Also (3) by conducting *cyanogen chloride* into the alcohols:

$$N{:}CCl+2C_2H_5.OH=H_2N.COOC_2H_5+C_2H_5Cl;$$

(4) by the direct union of *cyanic acid* with the alcohols:

$$NH{:}CO+C_2H_5.OH=H_2N.COOC_2H_5.$$

When an excess of cyanic acid is employed, allophanic esters are also produced (p. 444); and (5) from urea chloride and the alcohols.

The urethanes are crystalline, volatile bodies, soluble in alcohol, ether and water. Sodium acts on their ethereal solution with the evolution of hydrogen; in the case of urethane it is probable that sodium urethane, $NHNa.COOC_2H_5$ or $NH:C(ONa)OC_2H_5$ (B. **23,** 2785), is produced. Alkalis decompose them into CO_2, ammonia and alcohols. They yield urea when heated with ammonia:

$$H_2NCO.OC_2H_5+NH_3=H_2NCO.NH_2+C_2H_5OH.$$

Conversely, on heating urea or its nitrate with alcohols, the urethanes are regenerated (C. 1900, II. 997).

Urethane, *Carbamic Ethyl Ester,* $NH_2CO_2C_2H_5$, m.p. 50°, b.p. 184°, crystallizes in plates; *methyl ester,* m.p. 50°, b.p. 177°; *propyl ester,* m.p. 53°, b.p. 195° Urethane is successfully employed as a soporific; but is surpassed in this characteristic by higher esters, such as *methyl propyl carbinol urethane, hedonal,* $NH_2COOCH(CH_3)(C_3H_7)$, m.p. 76°, b.p. 215° (C. 1900, I. 1208; II. 997; 1901, I. 1302); *allyl ester,* $NH_2COOC_3H_5$, m.p. 21°, b.p. 204°.

Acetyl Urethane, $CH_3CO.NHCO_2C_2H_5$, m.p. 78°, b.p._{72} 130°, is obtained from acetyl chloride and urethane. Hydrogen in it can be replaced by sodium. Alkyl iodides acting on the sodium compound produce *alkyl acetyl urethanes* (B. **25**, R. 640). When heated to 150° with urea, acetyl urethane passes into acetoguanamide, or methyl dioxytriazine, and with hydrazine it yields the triazolones (A. **288**, 318).

Chlor- and *brom-acetyl Urethane, α-Bromopropionyl Urethane,* etc., result from the action of sodium urethane on halogen fatty acid esters (B. **38**, 297).

Aminoformyl Glycollic Ester, $NH_2CO.OCH_2CO_2C_2H_5$, m.p. 61°, and *Aminoformyl Lactic Ester,* m.p. 65°, are obtained from the corresponding chloro-compounds (p. 430).

The *esters of these alkylated carbamic acids* are formed, like the urethanes, by (1) the action of carbonic or (2) chlorocarbonic esters on amines; and (3) on heating isocyanic esters (p. 461) with the alcohols to 100°:

$$CO{:}NC_2H_5+C_2H_5OH=C_2H_5NH.COOC_2H_5.$$

also (4) by the interaction of the chlorides of alkyl urea and the alcohols; (5) when alcohols act on acid azides (p. 160).

$$RCON_3+C_2H_5OH=RNHCOOC_2H_5+N_2.$$

Methyl Carbamic Ethyl Ester, $CH_3.HNCOOC_2H_5$, b.p. 170° (B. **28**, 855; **23**, 2785), can also be prepared from sodium urethane iodomethane.

Ethyl Carbamic Ethyl Ester, $C_2H_5HNCOOC_2H_5$, b.p. 175°.

Ethylene Urethane, $C_2H_5OCONHCH_2CH_2NHCOOC_2H_5$, m.p. 113°, is formed from ethylene diamine and $ClCO_2C_2H_5$ (B. **24**, 2268).

Hydroxyethyl Carbamic Anhydride, $\overline{OCH_2CH_2.NHCO}$, m.p. 90°, is prepared from brom-ethylamine hydrobromide, and silver or sodium carbonate (B. **30**, 2494).

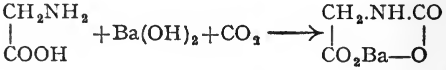
Alkylidene Urethanes and **Diurethanes.** *Hydroxymethyl Urethane,* $HOCH_2.NHCO_2C_2H_5$, is prepared from glycollic acid azide and alcohol (B. **34**, 2795). *Methylene Diurethane,* $CH_2(NHCO_2C_2H_5)_2$, m.p. 131°, is produced from urethane, formaldehyde, and a little hydrochloric acid, and when heated with more acid and acetic anhydride there is formed *anhydroformaldehyde urethane,* $(CH_2{:}NCO_2C_2H_5)_2$, m.p. 102° (B. **36**, 2206).

Ethylidene Diurethane, $CH_3CH(HNCOOC_2H_5)_2$, m.p. 126°, is prepared from urethane and acetaldehyde; it crystallizes in shining needles (B. **24**, 2268).

Chloral Urethane, $CCl_3.CH(OH)NHCO_2C_2H_5$, m.p. 103°, is formed from urethane and chloral. Acid anhydrides convert it into *Trichlorethylidene Urethane,* $CCl_3.CH:NCOOC_2H_5$, m.p. 143° (B. **27**, 1248).

Diurethane Glyoxylic Acid, $(C_2H_5OCONH)_2CHCO_2H$, m.p. 160°; *ethyl ester,* m.p. 143°, is prepared from glyoxylic ester, urethane and hydrochloric acid (C. 1906, II. 598).

Carbamic Acid derivatives of the Aminocarboxylic Acids and Peptides are of importance in the identification and synthesis of the latter bodies (p. 391). (1) Their Ca and Ba salts are obtained from the amino-acids in solutions of the alkali earths by the passage of CO_2 as more or less soluble crystalline precipitates:



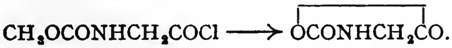
$$\begin{array}{l}CH_2NH_2\\ |\\ COOH\end{array}+Ba(OH)_2+CO_2\longrightarrow\begin{array}{l}CH_2.NH.CO\\ |\qquad\qquad\ |\\ CO_2Ba—O\end{array}$$

They readily decompose, reforming the amino-acid (B. **39**, 397; C. 1908, I. 1287).

(2) Esters are prepared from chlorocarbonic esters and alkaline solutions of amino-acids or their esters.

Carboxethyl Glycine, Urethane Acetic Acid, $C_2H_5O.CONHCH_2COOH$, m.p. 75°; *ethyl ester,* m.p. 28°, b.p.$_{12}$ 126°.

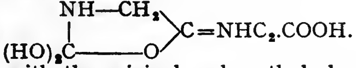
Carbomethoxy Glycine, $CH_3OCONHCH_2CO_2H$, m.p. 96°; *ethyl ester,* b.p.$_{18}$ 128°. Thionyl chloride converts these acids into unstable *chlorides,* $ROCONHCH_2COCl$, which, on warming, give off chloro-alkyl and are changed into *glycine anhydride :*



$$CH_3OCONHCH_2COCl \longrightarrow \overline{OCONHCH_2CO}.$$

The anhydride, treated with ice-cold barium hydroxide solution, yields the same compound as is obtained from the barium hydroxide solution of glycine when treated with CO_2. The anhydride on being heated loses CO_2 and polymerizes to *glycine anhydride,* $(NHCH_2CO)_x$ (B. **39**, 857). *Leucine Carbonic Anhydride,* $\overline{OCONHCH(C_4H_9)CO}$, m.p. 49° (B. **41**, 1725).

Carboxethyl Alanine, $C_2H_5OCONHCH(CH_3)COOH$, m.p. 84°; *ethyl ester,* b.p.$_{10}$ 123° (A. **340**, 127).

Carboxyethyl Glycyl Glycine Ester, $C_2H_5OCO.NHCH_2CONHCH_2COOC_2H_5$, m.p. 87°, is obtained from glycyl glycine ester (p. 392) and $ClCO_2R$; or from carboxyethyl glycine chloride (see above) and glycine ester. Hydrolysis liberates the free, dibasic *ψ-Glycyl Glycine Carboxylic Acid,* m.p. 208°, with decomposition. The remarkable solubility of this compound points to its being a ring compound of the formula  It yields a *diethyl ester,* m.p. 149°, isomeric with the original carboxethyl glycyl glycine ester, and a stable Ba salt, which is different from the unstable salt of the true glycyl glycine acid, prepared from glycyl glycine barium hydroxide and CO_2 (B. **40**, 3235).

Diglycyl Glycine Carboxylic Acid and *Triglycyl Glycine Carboxylic Acid* behave similarly (B. **36**, 2094).

Nitroso- and *Nitro-urethanes* are of interest, partly on account of their connection with the *diazo-* bodies (pp. 169, 213), with *nitramide* and other compounds.

Nitrosocarbamic Methyl Ester, $NO.NHCO_2CH_3$, m.p. 61° (A. **302**, 251). *Nitrosourethane,* $NO.NHCO_2C_2H_5$, m.p. 51°, with decomposition, is formed by reduction of ammonium nitro-urethane with glacial acetic acid and zinc dust (A. **288**, 304). The salts of these esters probably possess the formula $HO.N:NCO_2R$ (B. **32**, 3148; **35**, 1148).

Methyl Nitrosourethane, $ON.N(CH_3)CO_2C_2H_5$, is prepared from methyl urethane and nitrous acid. It is a liquid, which with alkalis yields diazomethane (p. 213) with the intermediate formation of $CH_3N:NOK$.

Nitrocarbamic Methyl Ester, $NO_2.NHCO_2CH_3$, m.p. 88° (A. **302**, 249). *Nitrourethane,* $NO_2.NHCO_2C_2H_5$, m.p. 64°, results from the action of ethyl nitrate on a cold solution of urethane in concentrated sulphuric acid. It is easily soluble in water, very easily in ether and alcohol, but with great difficulty in ligroïn. It shows a strongly acid reaction, whilst its salts are neutral: *Ammonium nitrourethane,* $NO_2N(NH_4)CO_2C_2H_5$; *potassium nitrourethane,* $NO_2NK.CO_2C_2H_5$ (A. **288**, 267). *Nitrocarbamic Acid,* $NO_2.NH.CO_2H$, liberated from its potassium salt by sulphuric acid at 0°, decomposes into CO_2 and *Nitramide,* NO_2NH_2, m.p. 72–85°. This is isolated by means of ether. *Potassium Nitrocarbamate,* NO_2NHCO_2K, results when potassium nitrourethane is treated with potassium hydroxide in methyl alcohol. It crystallizes in fine white needles.

Methyl Nitrourethane, $NO_2.N(CH_3)CO_2C_2H_5$, is formed from silver nitrourethane and iodomethane; also from methyl urethane. It is a colourless, pleasantly-smelling oil. It is decomposed by ammonia into methyl nitramine (p. 169).

Urea Chlorides, *Carbamic Acid Chlorides,* are produced by the interaction of phosgene gas and ammonium chloride at 400°; by action of $COCl_2$ on the hydrochlorides of the primary amines at 260–270°, and also on the secondary amines in benzene solution (B. **20**, 858; **21**, R. 293):

$$COCl_2+NH_3.HCl=ClCONH_2+2HCl.$$

Urea Chloride, *Carbamic Acid Chloride, Chlorocarbonic Amide,* $Cl.CONH_2$, m.p. 50°, b.p. 61–62°, when it dissociates into hydrochloric acid and isocyanic acid, HNCO. The latter partly polymerizes to *cyamelide.* Urea chloride undergoes a like change on standing.

Methyl Carbamyl Chloride, $ClCONH.CH_3$, m.p. 90°, b.p. 94°. *Ethyl Urea Chloride,* $ClCONH.C_2H_5$, b.p. 92°.

These compounds boil apparently without decomposition, yet they suffer dissociation into hydrochloric acid and isocyanic acid esters, which reunite on cooling:

$$COHCH_3+HCl=Cl.CONH.CH_3.$$

Dimethyl Urea Chloride, $Cl.CON(CH_3)_2$, b.p. 167° C. (see Tetramethyloxamide).

Diethyl Urea Chloride, $Cl.CON(C_2H_5)_2$, b.p. 190–195°, is obtained from diethyl oxamic acid by means of PCl_5.

Reactions.—(1) The urea chlorides are decomposed by water into CO_2 and ammonium chloride. (2) They yield urethanes with alcohols. (3) With amines they form *alkylic ureas :*

$$H_2NCOCl+2C_2H_5.NH_2=H_2NCONHC_2H_5+C_2H_5NH_2.HCl.$$

Nucleus-synthetic reactions : (4) With benzene and phenol ethers in the presence of $AlCl_3$ they yield acid amides :

$$ClCO.NH_2+C_6H_6 \xrightarrow{AlCl_3} C_6H_5CONH_2+HCl.$$

Carbamide, Urea, $CO{<}^{NH_2}_{NH_2}$, m.p. 132–133°, was discovered by *v. Rouelle* in urine in 1773, and was first synthesized from ammonium isocyanate by *Wöhler* in 1828 (*Pogg,* A. (1825) **3,** 177; (1828) **12,** 253). This brilliant discovery showed that organic as well as inorganic compounds could be built up artificially from their elements (p. 1). It occurs in various animal fluids, chiefly in the urine of mammals, and can be separated as nitrate from concentrated urine on the addition of nitric acid. It is present in small quantities in the urine of birds and reptiles. A full-grown man voids upon an average about 30 grams of urea daily. The formation of this substance is due to the decomposition of proteins. It may be prepared artificially: (1) by evaporating the aqueous solution of ammonium isocyanate, when an atomic transposition occurs (*Wöhler*):

$$CO:N.NH_4 \longrightarrow CO(NH_2)_2.$$

Mixed aqueous solutions of potassium cyanate and ammonium sulphate (in equivalent quantities) are evaporated ; on cooling, potassium sulphate crystallizes out and is filtered off, the filtrate being evaporated to dryness, and the urea extracted by means of hot alcohol. This is also a reversible process. On heating $\frac{1}{10}$n urea solution for some time to 100°, four to five per cent. of the urea will be changed to ammonium cyanate (B. **29**, R. 829 ; C. 1903, I. 139).

(2) When a solution of carbon monoxide in ammoniacal cuprous chloride solution is heated, copper is precipitated and urea is formed (C. 1899, I. 422):

$$CO+2NH_3+Cu_2Cl_2=CO(NH_2)_2+2HCl+2Cu.$$

It is also formed by the methods in general use in the preparation of acid amides: (3) by the action of ammonia (*a*) on carbamic esters or urethanes, (*b*) on dialkyl or diphenyl carbonic esters (B. **17,** 1826), and (*c*) on chlorocarbonic esters. The bodies mentioned under *b* and *c* first change to carbamic esters :

$$NH_2.CO_2C_2H_5+NH_3=NH_2CONH_2+C_2H_5OH$$
$$CO(OC_2H_5)_2+2NH_3=NH_2CONH_2+2C_2H_5OH$$
$$CO(OC_6H_5)_2+2NH_3=NH_2CONH_2+2C_6H_5OH \text{ (method of preparation)}$$
$$ClCO_2C_2H_5+3NH_3=NH_2CONH_2+C_2H_5OH+NH_4Cl.$$

(4) By the action of ammonia on phosgene and urea chloride:

$$COCl_2+4NH_3=CO(NH_2)_2+2NH_4Cl$$
$$ClCONH_2+3NH_3=CO(NH_2)_2+NH_4Cl.$$

(5) By heating ammonium carbamate or thiocarbamate to 130–140°.

The two following methods of formation show the genetic relation of urea with thiourea, cyanamide and guanidine:

(6) Potassium permanganate oxidizes thiourea to urea. (7) Small quantities of acids convert cyanamide into urea:

$$CNNH_2+H_2O=CO(NH_2)_2.$$

(8) Urea is formed when guanidine is boiled with dilute sulphuric acid or barium hydroxide solution:

$$NH{:}C(NH_2)_2+H_2O=CO(NH_2)_2+NH_3.$$

Urea crystallizes in long, rhombic prisms or needles, which have a cooling taste, like that of potassium nitrate. It can be easily obtained pure by one recrystallization from amyl alcohol (B. **26**, 2443). It dissolves in one part of cold water and in five parts of alcohol, and it is almost insoluble in ether. At high temperatures it decomposes (1) into ammonia, ammelide (p. 473), biuret (p. 445) and cyanuric acid. (2) When urea is heated above 100° with water, or when boiled with alkalis or acids, it decomposes into carbon dioxide and ammonia. The same decomposition occurs in the natural decomposition of urine.

(3) Nitrous acid decomposes urea, in the same manner that it decomposes all other amides:

$$CO(NH_2)_2+N_2O_3=CO_2+2N_2+2N_2O.$$

(4) An alkali hypobromite decomposes urea into nitrogen, carbon dioxide and water. If, however, urea is treated with NOCl-solution in presence of benzaldehyde, the *Hofmann transformation* takes place (comp. carboxylic amides, pp. 160, 276), and there results hydrazine carboxylic acid (p. 1) or hydrazine as a benzal derivative:

$$NH_2CONH_2+NaClO+C_6H_5CHO \longrightarrow C_6H_5CH{:}N.NHCOOH+NaCl+H_2O.$$

Salts: Urea, like glycocoll, forms crystalline compounds with acids, bases and salts. Although it is a diamide it combines with but one equivalent of acid, whereby one only of the amido-groups is neutralized by the acid radical.

Urea Nitrate, $CO(NH_2)_2.HNO_3$, forms leaf-like crystals, which are not very soluble in nitric acid. The *oxalate*, $[CO(NH_2)_2]_2(CO_2H)_2$, consists of thin leaflets, which are soluble in water.

On evaporating a solution containing both urea and sodium chloride, the compound, $CO(NH_2)_2.NaCl+H_2O$, separates in shining prisms.

"The extent of the decomposition of proteins in the animal body is one of the most fundamental questions of physiology." Urea is by far the most predominant of the nitrogenous decomposition products of proteins in mammalia and batrachia. Its accurate determination is, therefore, of the utmost importance.

The *Kjeldahl-Wilfarth* method is the best adapted for the estimation of nitrogen in the products of the metabolism. The method of *Liebig* may also be used for the determination of urea, which consists in titrating in neutral solution with mercuric nitrate (see B. **39**, 705), when a precipitate, consisting of a mixture of double compounds of carbamide and mercuric nitrate, separates, together with the simultaneous liberation of nitric acid. The *Knop-Hüfner* method consists in decomposing the urea with sodium hypobromite (see above). *Pflüger* and his students have critically examined all methods suggested for this purpose (comp. Arch. f. d. ges. Phys. **21**, 248; **35**, 199; **36**, 101, etc.).

Alkyl Ureas are produced according to the same reactions which yield urea (1) when primary or secondary amines act on isocyanic esters or isocyanic acid:

$$CO{:}NH+NH_2.C_2H_5=\underset{\text{Ethyl Urea.}}{NH_2CONHC_2H_5}$$

$$CO=NC_2H_5+NH(C_2H_5)_2=\underset{\text{Triethyl Urea.}}{N(C_2H_5)_2CONHC_2H_5}.$$

Alkyl ureas are formed, also, when isocyanic esters are heated with water —CO_2, and amines being produced (p. 462); the latter unite with the esters:

$$CO=NC_2H_5 \xrightarrow{H_2O} CO_2+NH_2C_2H_5 \xrightarrow{CONC_2H_5} CO(NHC_2H_5)_2.$$

(2) They are also obtained by the action of urea chloride and alkyl-urea chlorides on ammonia, and primary and secondary amines (p. 437), as well as by the action of phosgene on the latter.

(3) By the action of alkali hydroxides on the ureïdes, the urea derivatives containing acid radicals:

$$\underset{\text{Methyl Acetyl Urea.}}{CH_3.NHCONH.COCH_3}+KOH=\underset{\text{Methyl Urea.}}{CH_3.NHCONH_2}+CH_3CO_2K.$$

(4) By desulphurizing the alkyl thioureas with an alcoholic silver nitrate solution (B. **28**, R. 915).

Ureas of this class are perfectly analogous to ordinary urea so far as properties and reactions are concerned. They generally form salts with one equivalent of acid. They are crystalline salts, with the exception of those containing four alkyl groups. On heating those with one alkyl group, cyanic acid (or cyanuric acid) and an amine are produced. The higher alkylated members can be distilled without decomposition. Boiling alkalis convert them all into CO_2 and amines:

$$CH_3NH.CONH_2+H_2O=CO_2+NH_3+NH_2.CH_3.$$

Methyl Urea, $CH_3.NHCONH_2$, m.p. 102°, results on heating methyl acetourea (from acetamide by the action of bromine and potassium hydroxide) with potassium hydroxide.

Ethyl Urea, $C_2H_5.NHCONH_2$, m.p. 92°.

α-Diethyl Urea, $CO(NH.C_2H_5)_2$, m.p. 112°, b.p. 263°.

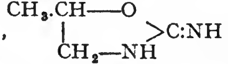
β-Diethyl Urea, $(C_2H_5)_2NCONH_2$, m.p. 70°.

Triethyl Urea, $(C_2H_3)_2NCONHC_2H_5$, m.p. 63°, b.p. 223°.

Tetraethyl Urea, b.p. 210–215°, has an odour resembling that of peppermint.

Tetrapropyl Urea, b.p. 258° (B. **28**, R. 155).

Allyl Urea, $C_3H_5NHCONH_2$, m.p. 85°, is converted by hydrogen bromide into *propylene-ψ-urea* (p. 446),



$$\begin{array}{l} CH_3.CH—O \\ \quad | \qquad\qquad >C{:}NH \\ CH_2—NH \end{array}$$

(B. **22**, 2990; C. 1898, II. 766).

Diallyl Urea, *Sinapoline*, $CO(NH.C_3H_5)_2$, m.p. 100°, is formed when *allyl isocyanic ester* is heated with water, or by heating mustard oil with water and lead oxide. *Diallyl thiourea* is first formed, but the lead oxide desulphurizes it (p. 452).

Carbamido-ethyl Alcohol, $HOCH_2CH_2.NHCONH_2$, m.p. 95°, is obtained from hydroxyethylamine isocyanate or 2-amino-ethanol (B. **28**, R. 1010).

Cyclic Alkylene Urea Derivatives.

The ureas and aldehydes combine at the ordinary temperature, with loss of water, to yield the following compounds:

Methylene Urea, $CO{<}^{NH}_{NH}{>}CH_2$, consists of white, granular crystals (B. **29**, 2751; C. 1897, II. 736).

Ethylidene Urea, $CO{<}^{NH}_{NH}{>}CHCH_3$, m.p. 154°, is decomposed, by boiling, into its component parts. When HCl gas is passed into a mixture of acetone and urea, there is formed *triacetone diurea*, $(CH_3)_2C[NHCON{:}C(CH_3)_2]_2+3H_2O$, m.p. 265–268° with decomposition (B. **34**, 2185).

Ethylene Urea, $CO{<}^{NHCH_2}_{NHCH_2}$, m.p. 131°, isomeric with ethylidene urea, is produced on heating ethyl carbonate with ethylene diamine at 180°. It is also formed, together with hydantoïn (p. 442), when parabanic acid or oxalylurea is electrolytically reduced (B. **34**, 3286).

Nitric acid produces *ethylene dinitrourea*. The union of ethylene diamine and hydrocyanic acid, however, gives rise to *ethylene diurea*, $NH_2CONH.CH_2$-$CH_2NHCONH_2$.

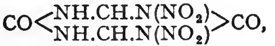
Trimethylene Urea, $CH_2{<}^{CH_2NH}_{CH_2NH}{>}CO$, m.p. 260°, is obtained from ethyl carbonate and trimethylene diamine; or by the electrolytic reduction of barbituric acid and related compounds (see Malonyl Urea). Similarly, the reduction of methyl uracil (p. 416) produces *methyl trimethylene urea*, $CH_2{<}^{CH(CH_3)NH}_{CH_2\text{——}NH}{>}CO$, m.p. 201° (B. **33**, 3378; **34**, 3286).

Very little is known relative to the action of urea on *dialdehydes*, *aldehyde-ketones*, and *diketones*: *Acetylene Diurea*, *Glycoluril*, $C_3H_6N_4O_2$, is obtained from glyoxal and urea, as well as by the reduction of allantoïn (B. **19**, 2477).

Nitric acid converts it into *Dinitroglycoluril*, *Acetylene Dinitrodiureïne*, decomposes at 217°, and when boiled with water passes into *glycolureïne*, $C_3H_6N_2O_3$, isomeric with hydantoïc acid.


$CO{<}^{NH.CH.NH}_{NH.CH.NH}{>}CO$,

Glycoluril (?).


$CO{<}^{NH.CH.N(NO_2)}_{NH.CH.N(NO_2)}{>}CO$,

Dinitroglycoluril.


$CO{<}^{NH.CHOH}_{NH.CHOH}$

Glycolureïne.

Consult B. **26**, R. 291, for the action of urea on *acetyl acetone*.

Nitrosoureas are formed when nitrites act on the nitrates or sulphates of ureas which contain an alkyl group in the amido group:

Nitroso-methyl Urea, $NH_2.CO.N(NO)CH_3$. *Nitroso-a-diethyl Urea*, $NH(C_2H_5)$-$CON(NO)C_2H_5$, m.p. 5°, is a yellow oil at the ordinary temperature. The reduction of these compounds gives rise to the *semicarbazides* or *hydrazine ureas*, which yield *alkyl hydrazines* (p. 169) when they are decomposed.

Nitrourea, $NO_2.NHCONH_2$, is produced when urea nitrate is introduced into concentrated sulphuric acid. It forms a white, crystalline powder when recrystallized from water. This melts at higher temperatures with decomposition. It is a strong acid; its alkali salts are neutral in reaction, and it expels acetic acid from acetates (A. **288**, 281).

Nitro-ethyl Urea, $NO_2.NHCONH.C_2H_5$, m.p. 130–131°.

DERIVATIVES OF UREA WITH ORGANIC ACID RADICALS: UREÏDES

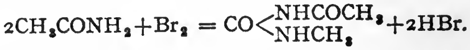
The urea derivatives of the monobasic carboxylic acids are obtained by the action of acid chlorides or acid anhydrides on urea. By this procedure, however, it is possible to introduce but one radical. The compounds are solids; they decompose when heat is applied to them, and do not form salts with acids. Alkalis cause them to separate into their components.

Formyl Urea, $NH_2CONH.CHO$, m.p. 167° (B. **29**, 2046).

Acetyl Urea, $NH_2CONH.COCH_3$, m.p. 218°, (A **229**, 30; C. 1898, II. 181), is is not very soluble in cold water and alcohol. It forms long, silky needles. (Consult B. **28**, R. 63, for the metal derivatives of formyl and acetyl urea.) Heat breaks it up into acetamide and isocyanuric acid. *Chloracetyl Urea*,

$H_2NCONH.COCH_2Cl$, decomposes about 160°. *Bromacetyl Urea,* NH_2CO-$NH.COCH_2Br$, dissolves with difficulty in water. When heated with ammonia it changes to hydantoïn. The *ureïdes* of the *dialkyl acetic acids,* such as $(C_2H_5)_2CHCONHCONH_2$, m.p. 207°, are also obtained from dialkyl malonic acid (p. 491) and urea by means of phosphorus chloride, etc. (C. 1903, II. 813).

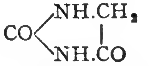
Methyl Acetyl Urea, $CH_3.NHCONH.COCH_3$, m.p. 180°, is obtained from methyl urea upon digesting it with acetic anhydride ; and by the action of bromine and potassium hydroxide on acetamide (p. 159) :



$$2CH_3CONH_2+Br_2 = CO\begin{matrix}\diagup NHCOCH_3\\ \diagdown NHCH_3\end{matrix}+2HBr.$$

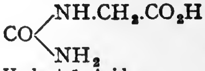
Diacetyl Urea, $CO(NH.COCH_3)_2$, results when $COCl_2$ acts on acetamide, and sublimes in the form of needles without decomposition.

Ureïdes of Hydroxyacids.—Open and closed chain and ring-shaped or cyclic ureïdes are known. This is especially true of α-hydroxyacids, like glycollic, lactic, and α-hydroxyisobutyric acids. As the open-chain ureïdes are obtained from the closed-chain members by severing a lactam-union by means of alkalis or alkali earths:



$$CO\begin{matrix}\diagup NH.CH_2\\ \diagdown NH.CO\end{matrix}$$

Hydantoïn,
Closed-chain Ureïde
of Glycollic Acid.



$$CO\begin{matrix}\diagup NH.CH_2.CO_2H\\ \diagdown NH_2\end{matrix}$$

Hydantoïc Acid,
Open-chain Ureïde
of Glycollic Acid.

Hydantoïn, *Glycolyl Urea,* $C_3H_4O_2N_2=\underset{\alpha}{CO}.\underset{\beta}{NH}.\underset{\gamma}{CH_2}.\underset{\delta}{CO}.\underset{\epsilon}{NH}$, m.p. 216°, possesses the same series of C and N atoms as the *glyoxalines* or *imidazoles* (p. 347), but the ring is less stable than the glyoxaline ring. It is prepared (1) by reduction, by means of hot hydriodic acid, of *allantoïn* (*q.v.*) and *alloxan* (*q.v.*), both important oxidation products of urea. Also, by electrolytic reduction of *parabanic acid* (oxalyl urea) (B. 34, 3286). (2) It is synthetically produced from *bromacetyl urea* (see above) by heating it with alcoholic ammonia, whereby it gives up hydrobromic acid. (3) Also, by the action of urea on dihydroxy-tartaric acid (A. 254, 258). (4) Finally, by evaporating a solution of hydantoïc acid ester (p. 443) with hydrochloric acid (method of preparation).

Chlorine produces *dichlorohydantoïn,* $C_3H_2Cl_2O_2N_2$, m.p. 121°. Bromine gives rise to a body which easily changes into *parabanic acid* (see above) (A. 327, 355; 348, 85). Concentrated nitric acid produces *β-nitrohydantoïn,* $CO.N(NO_2)CH_2CO.NH$, m.p. 170°, which on being boiled with water evolves CO_2 and is converted into nitro-amido-acetamide (B. 22, R. 58). Only the β-NH-group is substituted on nitration. *β-Acetyl Hydantoïn,* $CON(COCH_3)CH_2CONH$, m.p. 144°, is prepared from hydantoïn and acetic anhydride; it cannot be nitrated (A 327, 353).

When boiled with barium hydroxide solution hydantoïn is converted into glycoluric acid or hydantoïc acid:

$$CO.NH.CH_2.CO.NH+H_2O=H_2N.CONH.CH_2.COOH.$$

Hydantoïc Acid, *Glycoluric Acid,* $NH_2CONH.CH_2CO_2H$, was originally obtained from uric acid derivatives (allantoïn, glycouril, hydantoïn), but may be synthesized by heating urea with glycocoll to 120°, by boiling it with barium hydroxide solution (B. **39,** 2954), or by digesting glycocoll sulphate with potassium isocyanate, analogous to urea (p. 438).

Hydantoïc acid is very soluble in hot water and alcohol. When heated with hydriodic acid it yields CO_2, NH_3 and glycocoll; *ethyl ester,* m.p. 135°, is easily obtained by the addition of potassium cyanate to glycocoll ester hydrochloride (B. **33,** 3418). It is also formed from glycine ester and sodium methane (B. **38,** 305).

Hydantoïn Homologues.—For nomenclature, comp. the hydantoïn formula (p. 442) and also **A. 327,** 355. Hydantoïn, iodo-alkyls, and alkali give rise to *ε-alkyl hydantoïns,* in which the NH-group between the two CO-groups is alkylated (see also B. **22,** 685; **25,** R. 327).

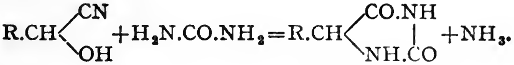
The *β-alkyl hydantoïns* are formed when urea is fused together with mono-alkylic glycocolls.

ε-Methyl Hydantoïn, $CONHCH_2CONCH_3$, m.p. 184°, is formed from silver hydantoïn and iodomethane. Nitric acid converts it into *β-Nitro-ε-methyl Hydantoïn,* m.p. 168° (A. **361,** 69). *ε-Ethyl Hydantoïn,* m.p. 102°.

β-Methyl Hydantoïn, $CO.N(CH_3).CH_2.CO.NH$, m.p. 157°, was first obtained from creatinine, and is also formed when sarcosine (p. 387) is heated with urea; or by heating the sarcosine with cyanogen chloride (B. **15,** 2111).

β-Ethyl Hydantoïn, m.p. 100°, sublimes readily.

The **γ-Alkyl Hydantoïns** may be synthesized by heating the cyanhydrins of the aldehydes and ketones (p. 379) with urea (see α-Phenyl Hydantoïn, and B. **21,** 2320):



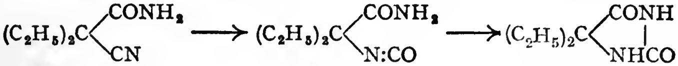
$$\mathrm{R.CH}{<}\begin{matrix}\mathrm{CN}\\ \mathrm{OH}\end{matrix}+\mathrm{H_2N.CO.NH_2}=\mathrm{R.CH}{<}\begin{matrix}\mathrm{CO.NH}\\ |\\ \mathrm{NH.CO}\end{matrix}+\mathrm{NH_3}.$$

α-Alkyl Hydantoïn.

α-Lactyl Urea, *γ-Methyl Hydantoïn,* $CO.NH.CH(CH_3)CO.NH+H_2O$, m.p. 140–145° (anhydrous) is formed, together with alanine from aldehyde ammonia by the action of potassium isocyanide containing potassium cyanide. Also, by the action of warm hydrochloric acid on *α-Lacturamic Ester* (α-carbamidopropionate), $NH_2CONHCH(CH_3)CO_2C_2H_5$, m.p. 94°, the product of alanine ester hydrochloride and potassium cyanate. Lactyl urea when boiled with barium hydroxide solution yields lacturamic acid, m.p. 155°. With 2 molecules of bromine it is converted into *Bromopyruveïde,* $BrCH:CNHCONHCO$, m.p. 242°, which unites with excess of lactyl urea to form *Pyruvic Ureïde,* $C_8H_8N_4O_6$. *γβ-Dimethyl Hydantoïn,* m.p. 221°, and *γβ-Methyl Ethyl Hydantoïn,* m.p. 85°, is prepared from N-methyl alanine and N-ethyl alanine respectively, potassium cyanate, and hydrochloric acid. *γ-Ethyl Hydantoïn,* m.p. 118°, is obtained from α-aminobutyric acid (A. **348,** 50). *γ-Isobutyl Hydantoïn,* m.p. 210°. *Isobutyl Hydantoïc Acid* is prepared from leucine, urea, and barium hydroxide solution; it is employed in the identification of leucine on account of its slight solubility (p. 389) (B. **39,** 2953).

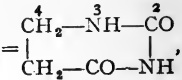
α-Isobutyryl Urea, *γ-Dimethyl Hydantoïn,* $CONH.C(CH_3)_2CONH$, m.p. 175°, is produced from acetone, hydrocyanic acid, and cyanic acid (A. **164,** 264); also from pinacolyl sulphourea (p. 452) and $KMnO_4$, *α-Carbimidoisibutyric Acid,* $NH_2CO.NHC(CH_3)_2COOH$, m.p. 155–160°; both these substances are ureïdes of α-hydroxyisobutyric acid.

γ-Dialkyl Hydantoïns, *e.g. γ-Diethyl Hydantoïn,* m.p. 165°, can also be prepared from cyanacetamide, by converting the latter into diethyl cyanacetamide, and treating this with bromine and alkali solution (Gaz. Chim. ital, **26,** I. 197):

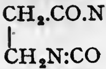


$$(\mathrm{C_2H_5})_2\mathrm{C}{<}\begin{matrix}\mathrm{CONH_2}\\ \mathrm{CN}\end{matrix}\longrightarrow(\mathrm{C_2H_5})_2\mathrm{C}{<}\begin{matrix}\mathrm{CONH_2}\\ \mathrm{N{:}CO}\end{matrix}\longrightarrow(\mathrm{C_2H_5})_2\mathrm{C}{<}\begin{matrix}\mathrm{CONH}\\ |\\ \mathrm{NHCO}\end{matrix}$$

Diethyl Cyanacetamide. Intermediate product. Diethyl Hydratoïn.

β-Lactyl Urea, *Hydrouracil,* $C_4H_6N_2O_2=$ 

$$\begin{array}{lcr} \overset{4}{C}H_2-\overset{3}{N}H-\overset{2}{C}O \\ | \qquad\qquad | \\ \underset{5}{C}H_2-\underset{6}{C}O-\underset{1}{N}H \end{array}$$

, m.p. 275°, is obtained similarly to diethyl hydantoïn, by treating succinic diamide with bromine and alkali, through an unstable intermediate product, 

$$\begin{array}{l} CH_2.CO.NH_2 \\ | \\ CH_2N:CO \end{array}$$

. It has been obtained by several other methods. It results, together with trimethylene urea, from the electrolytic reduction of *barbituric acid* (malonyl urea), of *dialuric acid* (tartronyl urea), and of *uramil* (aminomalonyl urea) (B. **34,** 3286). Further, by heating acrylic acid with urea at 210–220°, and from β-aminopropionic acid and cyanic acid (B. **38,** 635). 5-*Methyl Hydrouracil,* $(CH_3)C_4H_5N_2O_2$, m.p. 265°, and 4-*Methyl Hydrouracil,* m.p. 220°, are similarly prepared by heating urea with methyl acrylic acid and crotonic acid. 4-Methyl hydrouracil is also produced from β-aminobutyric acid and urea, and from β-aminobutyric ester and cyanic acid.

Bromine in glacial acetic acid yields *bromo*-derivatives of hydrouracil, which easily give up HBr, and are converted into *uracils* (B. **34,** 3751, 4129; **38,** 636).

The uracils or ureïdes of β-aldehydo- and keto-carboxylic acids, together with those of glyoxylic, oxalic, malonic, tartronic, and mesoxalic acids, will be considered later in connection with uric acid.

Di- and Tri-carboxylamide Derivatives. *Ureïdes of Carbonic Acid.*—Free dicarbamidic or imidodicarbonic acid and the free tricarbamic acids or nitrogen tricarboxylic acids are as unstable as free carbaminic acid itself (p. 435); but the esters, amides, and nitriles of these acids are known. They sustain the same relation to carbamic acid that diglycolamidic acid bears to glycocoll:

$NH_2.CH_2CO_2H$	$NH\begin{cases}CH_2CO_2H\\CH_2CO_2H\end{cases}$	$N\begin{cases}CH_2COOH\\CH_2COOH\\CH_2COOH\end{cases}$
Aminoacetic Acid.	Iminodiacetic Acid.	Nitrilotriacetic Acid.
(NH_2COOH)	$\left(NH\begin{cases}COOH\\COOH\end{cases}\right)$	$\left(N\begin{cases}CO_2H\\CO_2H\\CO_2H\end{cases}\right)$
Carbamic Acid.	Dicarbamidic Acid, Iminodicarboxylic Acid.	Tricarbamidic Acid, Nitrilotricarboxylic Acid.

Dicarbamidic Ester, *Imidodicarboxylic Ester,* $NH(CO_2C_2H_5)_2$, m.p. 50°, b.p. 215°, results when $ClCO_2C_2H_5$ acts on 2 molecules of sodium urethane; from nitrogen tricarboxylic ester by decomposition with alkali; and from carboxethyl isocyanate (p. 463) and alcohol. The ester yields a *sodium salt,* $NaN(CO_2R)_2$, more readily than urethane and acetyl urethane (p. 436) (B. **36,** 736; **39,** 686).

Allophanic Acid, $NH_2CONH.CO_2H$, is not known in a free state. A *disodium salt* of this acid, $NH_2CON(Na)CO_2Na$, appears to be formed when a benzene solution of urethane is boiled in the presence of sodium (B. **35,** 779). Its esters are formed (1) when chlorocarboxylic esters (1 mol.) act on urea (2 mols.) (B. **29,** R. 589); (2) by passing cyanic acid vapours into anhydrous alcohols (p. 461). At first carbamic acid esters are produced; these combine with a second molecule of cyanic acid and yield allophanic esters (B. **22,** 1572):

$$HNCO+NH_2.CO_2C_2H_5=NH_2CONH.CO_2C_2H_5.$$

From carbamic esters or urethanes (3) by the action of urea chloride (B. **21,** 293); (4) carbonyl chloride (B. **19,** 2344) or (5) with thionyl chloride (B. **26,** 2172):

$$2NH_2CO_2C_2H_5+SOCl_2=NH_2CONH.CO_2C_2H_5+HCl+SO_2+C_2H_5Cl.$$

For the formation of allophanic esters by decomposition of α-hydroxy-acid azides (see B. **34,** 2794). Nitrogen tricarboxylic ester and also carboxyethyl isocyanate (pp. 445, 463) with ammonia, yield allophanic ester (B. **39,** 686).

Allophanic Ethyl Ester, $NH_2CONHCO_2C_2H_5$, m.p. 191°; *propyl ester*, m.p. 155°; *amyl ester*, m.p. 162°.

The allophanic esters dissolve with difficulty in water, and, when heated, split up into alcohol, ammonia, and cyanuric acid. The allophanates are obtained from them by means of the alkalis or barium hydroxide solution. They show an alkaline reaction and are decomposed by carbon dioxide. On attempting to free the acid by means of mineral acids, it at once breaks up into CO_2 and urea.

Cyanamidocarbonic Acid, Cyanocarbamic Acid, $CN.NHCO_2H$, is the corresponding nitrile acid of allophanic acid. Its salts are formed by the addition of CO_2 to salts of cyanamide (A. **331**, 270):

$$2CN.NHNa + CO_2 = NC.N{:}C(ONa)_2 + CN.NH_2.$$

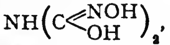
The *esters* of this acid result by the action of alcoholic potassium hydroxide on esters of *cyanamidodicarboxylic acid.*

Biuret, *Allophanamide*, $NHCONH_2CONH_2 + H_2O$, m.p. 190° (anhydrous), is formed on heating the allophanic esters with ammonia to 100°, or urea to 150–160°:

$$NH_2CONH_2 = NH_2CO.NH.CONH_2 + NH_3.$$

It is readily soluble in alcohol and water, and decomposes, when heated, into NH_3 and cyanuric acid. Heated in a current of HCl, biuret decomposes into NH_3, CO_2, cyanuric acid, urea, and guanidine. The aqueous solution, containing KOH, is coloured a violet red by copper sulphate. (The biuret reaction: C. 1898, I. 375; B. **35**, 1105; A. **352**, 73.)

Mononitrobiuret, $NH_2CO.NH.CO.NH.NO_2$, m.p. 105° with decomposition, is converted by hydrochloric acid and zinc dust into *Aminobiuret*, the hydrochloride of which when boiled with water gives urazole (p. 448), and when treated with sodium nitrite yields *Allophanic Acid Azide*, $NH_2CO.NHCON_3$ (A. **303**, 93).

Imidodioximidocarbonic Acid,  $NH\left(C{<}\begin{smallmatrix}NOH\\OH\end{smallmatrix}\right)_2$, m.p. 65–70°, is prepared from $Hg(CH_3)_2$ and nitrogen peroxide (C. 1898, II. 1015).

Carbamic Cyanide, Cyanourea, $NH_2CONH.CN$, the half nitrile of biuret, is formed, like urea, from guanidine, as well as from cyanoguanidine or dicyandiamide (p. 457), by the action of barium hydroxide solution; when digested with mineral acids it yields *biuret* (B. **8**, 708). (See B. **25**, 820, for alkyl cyanureas.)

Carbonyl Diurethane, $CO(NHCOOC_2H_5)_2$, m.p. 107°, is prepared from urethane (C. 1897, II. 25) and urea by the action of phosgene at 100°; also from carboxethyl isocyanate (p. 463) and water.

Carbonyl Diurea, $CO(NHCONH_2)_2$, m.p. 231°, is also produced from urethane (C. 1897, II. 25), and urea with phosgene at 100°. When heated it passes directly into NH_3 and cyanuric acid (p. 463) (B. **29**, R. 589).

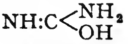
Carbonyl Dimethyl Urea, $CO(NHCONH.CH_3)_2$, m.p. 197°, similarly to the above, yields n-methyl cyanuric acid, on being heated (B. **30**, 2616).

Tricarbamidic Ester, Nitrogen Tricarboxylic Ester, $N(COOC_2H_5)_3$, b.p.$_{12}$ 147°, is prepared from sodium urethane or sodium imidodicarboxylic ester and chlorocarbonic ester. It is a colourless and odourless oil, scarcely soluble in water.

For the action of alkali and of P_2O_5, see next paragraph.

Cyanimidodicarboxylic Ester, Nitrogen Tricarboxylic Di-ester Nitrile, $N{:}C{-}N{=}(CO_2C_2H_5)_2$, results from the interaction of sodium cyanamide, CNNHNa, and chlorocarbonic ester. Alkali decomposes it into a carboxethyl group; P_2O_5 causes the liberation of CO_2 and $2C_2H_4$, leaving carboxethyl isocyanate (J. pr. Ch. [2] **16**, 146; B. **39**, 686).

Derivatives of Imidocarbonic Acid.—The pseudo-forms, imidocarbonic acid and pseudo-urea, correspond with carbamic acid and urea:

$NH_2.COOH$	$NH{:}C(OH)_2$	$CO(NH_2)_2$	 $NH{:}C{<}\begin{smallmatrix}NH_2\\OH\end{smallmatrix}$
Carbamic Acid.	**Imidocarbonic Acid.**	**Urea.**	**ψ-Urea.**

These modifications are not known in a free state, but many derivatives may be referred to them.

Imidocarbonic Ester, $HN{:}C(OC_2H_5)_2$, b.p.$_{36}$ 62°, is produced by reducing chlorimidocarbonic ester (B. **19**, 862, 2650); from di-imido-oxalic ester (p. 486) by the action of alcoholic sodium ethoxide (B. **28**, R. 760), and from cyanogen chloride (p. 465) by the same reagent. At 200° it breaks down into alcohol and cyanuric ether (B. **28**, 2466).

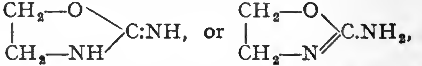
Chlorimidocarbonic Ethyl Ester, $\mathrm{ClN{:}C(OC_2H_5)_2}$, m.p. 39°, and the *methyl ester*, m.p. 20°, are produced in the action of esters of hypochlorous acid (p. 141) on a concentrated potassium cyanide solution. They are solids, with a peculiar penetrating odour, and distil with decomposition. Alkalis have little effect upon them, whilst acids break them up quite easily, forming ammonia, esters of carbonic acid and nitrogen chloride.

Bromimidocarbonic Ethyl Ester, $\mathrm{BrN{:}C(OC_2H_5)_2}$, m.p. 43°, results when bromine acts on imidocarbonic ester (B. **28**, 2470).

Ethyl Imidochlorocarbonic Ester, $\mathrm{C_2H_5N{:}CCl(OC_2H_5)}$, b.p. 126°, is formed by the union of ethyl isocyanide (p. 248) with ethyl hypochlorite (B. **28**, R. 760).

Derivatives of ψ- or Iso-Urea.—*Methyl Isourea*, $\mathrm{NH{:}C}\begin{smallmatrix}\diagup\mathrm{OCH_3}\\ \diagdown\mathrm{NH_2}\end{smallmatrix}$, m.p. 45°, b.p.$_9$ 82°, and *Ethyl Isourea*, $\mathrm{HN{:}C(OC_2H_5)NH_2}$, m.p. 42°, b.p.$_{15}$ 96°, are formed as *hydrochlorides* by the action of alcohols on equimolecular quantities of cyanamide and hydrochloric acid: $\mathrm{N{:}CNH_2} \xrightarrow[\mathrm{CH_3OH}]{\mathrm{HCl}} \mathrm{HN{:}C(NH_2)(OCH_3)HCl}$. The hydrochlorides are decomposed when heated in aqueous solution into chloromethane and urea. A similar decomposition occurs with the numerous derivatives of these substances. These ψ-urea ethers can also be considered as being *alkoxy-formamidines* or *aminoformimido-ethers*. Chlorocarbonic ester produces O-*methyl allophanic ester*, $\mathrm{CH_3OC(NH_2)NCO_2C_2H_5}$, m.p. 5°; isocyanic acid, O-*methyl biuret*, $\mathrm{CH_3OC(NH)NCONH_2}$, m.p. 118°; acetoacetic ester, O-*methyl methyl uracil* (p. 416); oxalic ester, O-*methyl parabanic acid*. Hydrochloric causes these substances to decompose into chloromethane and allophanic ester, biuret, methyl uracil, and parabanic acid. *Acetyl Methyl Isourea*, $\mathrm{CH_3O.C(NH_2)}$-$\mathrm{NCOCH_3}$, m.p. 58° (C. 1904, II. 29; B. **38**, 2243).

Ethylene ψ-Urea,



$\begin{matrix}\mathrm{CH_2{-}O}\\ |\\ \mathrm{CH_2{-}NH}\end{matrix}\!\!>\!\mathrm{C{:}NH}$, or $\begin{matrix}\mathrm{CH_2{-}O}\\ |\\ \mathrm{CH_2{-}N}\end{matrix}\!\!\geqslant\!\mathrm{C.NH_2}$,

is produced by the action of bromethylamine hydrobromide on potassium cyanate. It is an oil of basic character, which solidifies with difficulty (B. **31**, 2832).

Propylene ψ-Urea, $\mathrm{C_3H_6{:}CON_2H_2}$, results from bromopropylamine hydrochloride and potassium cyanate; as well as from *allyl urea*, by a molecular rearrangement induced by hydrobromic acid (B. **22**, 2991; C. 1898, II. 760).

HYDRAZINE-, AZINE-, AND AZIDO-DERIVATIVES OF CARBONIC ACID

Hydrazine Carboxylic Acid, $\mathrm{NH_2NHCOOH}$ or $\overline{\mathrm{NH_3NHCOO}}$ is precipitated when $\mathrm{CO_2}$ is passed into a cold aqueous solution of hydrazine, in the form of a white powder. It decomposes at 90° into $\mathrm{CO_2}$ and the *hydrazine salt* of *hydrazine-carboxylic acid*, $\mathrm{NH_2NHCO_2.N_2H_5}$, m.p. 70° (appr.), b.p.$_{23}$ 75° (appr.). *Sodium Benzalhydrazine Carbonate*, $\mathrm{C_6H_5CH{:}NNHCO_2Na}$, is prepared from urea, NaClO, and benzaldehyde (comp. p. 439).

Hydrazine Carboxylic Ethyl Ester, $\mathrm{NH_2NHCO_2C_2H_5}$, b.p.$_{18}$ 92°, is produced from nitro-urethane (p. 437) by reduction with zinc and acetic acid; also by the decomposition of nitrogen tricarboxylic ester with hydrazine. *Benzalhydrazine Carboxylic Ester*, m.p. 135° (A. **288**, 293; B. **36**, 745; **37**, 4523; C. 1905, I. 1222).

Azidocarbonic Methyl Ester, $\mathrm{N_3CO_2CH_3}$, b.p. 102°, is obtained from chlorocarbonic methyl ester and ammonium nitrate; as well as from hydrazine carboxylic acid and nitrous acid (J. pr. Ch. [2] **52**, 461; B. **36**, 2057).

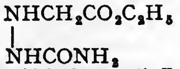
Semicarbazide, *Carbamic Hydrazide*, $\mathrm{\overset{1}{N}H_2.\overset{2}{N}H.\overset{3}{C}O.\overset{4}{N}H_2}$, m.p. 96°, is formed

(1) by heating urea and hydrazine hydrate to 100° (J. pr. Ch. [2] **52**, 465); (2) from hydrazine sulphate and potassium cyanide; (3) from amidoguanidine (B. **27**, 31, 56); (4) from nitrourea (A. **288**, 311). *Acetaldehyde Semicarbazone*, $NH_2CONH.N:CHCH_3$, m.p. 162°, is prepared from aldehyde ammonia and semicarbazide hydrochloride (A. **303**, 79). With benzaldehyde it yields *Benzal Semicarbazide*, $NH_2CONHN{=}CHC_6H_5$, m.p. 214°. *Acetone Semicarbazone*, $NH_2CONHN:C(CH_3)_2$, m.p. 187°, passes into bisdimethyl azimethylene (p. 228) (B. **29**, 611).

Acetoacetic Ester Carbazone, $NH_2CONHN:C(CH_3)CH_2CO_2C_2H_5$, m.p. 129° (A. **283**, 18), readily passes into a lactazam. Semicarbazide condenses with benzil to 1,2-diphenyl oxytriazine (Vol. II.). Semicarbazide is a reagent for aldehydes and ketones.

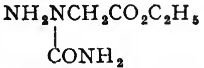
Alkyl Semicarbazides are obtained (1) by reduction of the nitroso-alkyl-ureas (p. 441); (2) from alkyl hydrazines by means of isocyanic acid or its esters, whereby the secondary NH-group receives the carbamide residue. The alkyl semicarbazides only react easily with the aldehydes when the hydrazine NH_2-group is free (C. 1901, I. 1170; B. **37**, 2318). *2-Methyl Semicarbazide*, $NH_2N(CH_3)$, $CONH_2$, m.p. 113°. *2,4-Methyl Ethyl Semicarbazide*, $NH_2N(CH_3)CONHC_2H_5$, is an oil. *1,2-Dimethyl Semicarbazide* $CH_3NHN(CH_3)CONH_2$, m.p. 116° (B. **39**, 3263).

Carbamidohydrazoacetic Ester, m.p. 122°, and *Aminohydantoïc Ester*, m.p. 70–74°, are prepared from hydrazinoacetic ester (p. 397) and cyanic acid (B. **31**, 167). *ε-Aminohydantoïn*, m.p. 244°, forms the partial result of the loss of alcohol to aminohydantoïc ester:



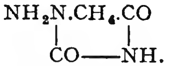
$$\begin{array}{l} NHCH_2CO_2C_2H_5 \\ | \\ NHCONH_2 \end{array}$$

Carbamidohydrazoacetic Ester.



$$\begin{array}{l} NH_2NCH_2CO_2C_2H_5 \\ \quad\;| \\ \quad CONH_2 \end{array}$$

Aminohydantoïc Ester.



$$\begin{array}{l} NH_2N.CH_4.CO \\ \quad\;|\qquad\;\; | \\ \quad CO{-\!\!-}NH. \end{array}$$

ε-Aminohydantoïn.

Carbohydrazide, $NH_2NH.CO.NHNH_2$, m.p. 152–153°, is obtained from the carbonic ester and hydrazine hydrate on heating to 100° (J. pr. Ch [2] **52**, 469). *Dibenzal Carbohydrazide*, $CO(NHN{=}CHC_6H_5)_2$, m.p. 198°.

Imidodicarboxylic Hydrazide, $NH(CONHNH_2)$, m.p. 200° with decomposition, is obtained from nitrogen tricarboxylic ester and hydrazine. It is easily decomposed into N_2H_4 and urazole (see below) (B. **36**, 744).

Hydrazodicarbonic Ester, Hydrazodicarboxylic Ester, $C_2H_5OCONHNHCOO.C_2H_5$, m.p. 130°, b.p. with decomposition about 250°, and is prepared from hydrazine and $Cl.CO_2C_2H_5$ (B. **27**, 773; J. pr. Ch. [2] **52**, 476).

Hydrazodicarbonamide, Hydrazoformamide, $NH_2CO.NHNH.CONH_2$, m.p. with decomposition 245°. It is obtained from potassium cyanate and salts of diamide or hydrazine: NH_2NH_2. It also results upon heating semicarbazide (B. **27**, 57), and from *Azodicarbonamide* (see below) by reduction. It yields the latter upon oxidation (A. **271**, 127; B. **26**, 405). NaOCl partially decomposes it into hydrazoic acid, carbon dioxide, and ammonia (J. pr. Ch. [2] **76**, 433).

Azodicarboxylic Acid, Azoformic Acid, $CO_2HN{=}NCO_2H$, is prepared from azodicarboxylic amide and concentrated potassium hydroxide solution, in the form of yellow needles. Its potassium salt deflagrates at 100°. It readily decomposes in aqueous solution into CO_2, potassium carbonate, diamide, and nitrogen. It is not possible to obtain from it the still unknown *diimide* $NH{=}NH$. *Diethyl Ester*, b.p.$_{18}$ 106°, is prepared from the hydrazo-ester (see above) and nitric acid. It is an orange-yellow oil.

Azodicarboxylic Amide, Azoformamide, $NH_2CON{=}NCONH_2$, is formed (1) by the oxidation of *hydrazodicarboxylic amide* with chromic acid, and (2) from *azodicarboxylic diamidine*, $NH_2C(NH)N:NC(NH)NH_2$ (p. 458). It is an orange-red powder.

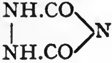
Carbamic Acid Azide, Azidocarbonic Amide, N_3CONH_2, m.p. 97°, is prepared from semicarbazide and nitrous acid; and by the combination of hydrazoic and cyanic acids. Silver nitrate decomposes it into silver cyanate and silver azide; when heated with water it is split up into N_3H, NH_3, and CO_2. Hydrogen sulphide reduces the azide to urea (A. **314**, 339). Hydrocyanic acid unites with it to form *urea azocyanide, carbamidocyanotriazene*, $NH_2CONHN:NCN$.

Carbodiazide, Carbazide, Nitrogen Carbonyl, $CO(N_3)_2$, is produced from carbohydrazide and nitrous acid:

$$CO(NHNH_2.HCl)_2+2KNO_2=CO(N_3)_2+2NaCl+4H_2O.$$

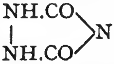
It forms spear-like, very volatile crystals, of a penetrating and stupefying odour, recalling that of phosgene (p. 430) and hydrazoic acid. It is explosive. The aqueous solution decomposes into CO_2 and $2N_3H$ (B. **27**, 2684; J. pr. Ch. [2] **52**, 482).

Cyclic Hydrazine Derivatives of Urea.—Urazole, *Hydrazodicarbonimide,*



$\begin{matrix} NH.CO \\ | \\ NH.CO \end{matrix}\!\!>NH$, m.p. 244°, forms on heating hydrazodicarbonamide to 200° (A. **283**, 16), or from urea and hydrazine sulphate heated to 120° (B. **27**, 409). It is a strong, monobasic acid. For its alkylation, see C. 1898, I. 38.

Aminourazole,

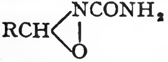


$\begin{matrix} NH.CO \\ | \\ NH.CO \end{matrix}\!\!>N.NH_2$, m.p. 270°, is probably the same as *diurea* or *bis-hydrazinocarboxyl,* which is obtained from hydrazo-dicarbonic ester and hydrazine hydrate at 100° (B. **46**, 2094).

Methenyl Carbohydrazide, $CO<^{NH.N}_{NH.NH}>CH$, m.p. 181°, is produced on heating carbohydrazide with orthoformic ester to 100° (J. pr. Ch. [2] **52**, 475).

Hydroxylamine Derivatives of Carbonic Acid.—Hydroxyurethane, $HO.NH\text{-}CO_2C_2H_5$, or $HON:C<^{OC_2H_5}_{OH}$, is a colourless liquid. It is produced when an hydroxylamine solution acts on chlorocarbonic ester (B. **27**, 1254).

Hydroxyl Urea, Carbamide Oxime, $NH_2CONH.OH$, m.p. 128°, is obtained from hydroxylamine nitrate and potassium isocyanate, together with a (? stereo-) isomeric body *Isohydroxyurea,* m.p. 70–72° with decomposition, and when heated in alcoholic solution it changes into the ordinary hydroxyl-urea. *Methyl Hydroxyl Urea,* $CH_3NHCO.NHOH$, m.p. 127° with decomposition, and *Ethyl Hydroxyl Urea,* m.p. 129° with decomposition, are formed from methyl and ethyl isocyanate and hydroxylamine (C. 1902, I. 31). *Dimethyl-nitroso-hydroxy-urea,* $(CH_3)_2NCO.\text{-}N(NO)OH$ (B. **30**, 2356). *Aldehyde* - derivative of *carbamide oxime,*



$RCH<\begin{matrix} NCONH_2 \\ | \\ O \end{matrix}$ (C. 1908, I. 948) dissolves readily in water and alcohol, but with difficulty in ether.

SULPHUR-CONTAINING DERIVATIVES OF CARBAMIC ACID AND OF UREA

The following compounds correspond with urethane and urea:

$CO<^{NH_2}_{SC_2H_5}$	$CS<^{NH_2}_{O.C_2H_5}$	$CS<^{NH_2}_{SC_2H_5}$	$CS<^{NH_2}_{NH_2}$ or $NH:C<^{NH_2}_{SH.}$
Thiocarbamic Ester.	Sulphocarbamic Ester.	Dithiocarbamic Ester.	Sulphourea or Thiourea.

Many reactions of sulphourea indicate that its constitution is probably best expressed by a formula analogous to one of the non-existing pseudo forms of urea (p. 446).

Alkyl and aryl ethers are derived from *imidothiocarboxylic acid,* $NH:C<^{OH}_{SH}$ and *imidodithiocarboxylic acid,* $NH:C<^{SH}_{SH}$.

Thiolcarbamic Acid, Carbamine-thiolic Acid, $CO<^{NH_2}_{SH}$, is not known in the free state. Its *ammonium salt,* $CO<^{NH_2}_{SNH_4}$, is prepared by leading COS into alcoholic ammonia (A. **285**, 173). It is a colourless, crystalline mass, which is unstable on exposure to the air. When heated to 130° it breaks up into hydrogen sulphide and urea.

Alkylamines and COS yield alkyl ammonium salts of alkyl carbamine-thiolic acids, such as *ethyl carbamine-thiolic acid,* $C_2H_5.NH.CO.SH$, and *isobutyl carbamine-thiolic acid,* $C_4H_9NH.COSH$. The mercury salts of these two acids decompose when heated into isocyanic esters and dialkyl ureas (comp. p. 462) (A. **359**, 202).

Thiol-carbamic Methyl Ester, NH_2COSCH_3 or $NH{:}C{<}\substack{OH \\ SCH_3}$, m.p. 95°, and *ethyl ester*, m.p. 108°, both result from the action of ammonia (1) on *dithiocarbonic ester* (p. 431), (2) on chlorocarbonic thiolic ester; (3) by the passage of HCl into a solution of potassium or alkyl thiocyanate (B. **14**, 1083) in alcohol, when sulphocarbamic ester is also formed (J. pr. Ch. [2] **16**, 358).

These are crystalline compounds which dissolve with difficulty in water.

Thiol-carbethylamine Ethyl Ester, $C_2H_5NH.COSC_2H_5$, b.p. 204–208°. It results from the union of ethyl isocyanate with ethyl mercaptan.

Sulphocarbamic Acid, *Xanthogenamic Acid, Thiocarbamic Acid*, $NH_2.CSOH$, is known in its alkyl compounds,

The **esters** of *sulphocarbamic acid—thiourethanes*, the *xanthogenamides*—are formed when alcoholic ammonia acts on the xanthic esters (p. 433):

$$C_2H_5S.CSOC_2H_5+NH_3=NH_2.CSOC_2H_5+C_2H_5SH.$$

The *ethyl ester* of sulphocarbamic acid, m.p. 38°, as well as the *methyl ester*, m.p. 43°, are both slightly soluble in water. Both esters decompose into mercaptans, cyanic acid and cyanuric acid when heated. Alcoholic alkalis decompose them into alcohols and thiocyanates.

The *alkyl thiocarbamic esters* are obtained when the mustard oils are heated to 110° with anhydrous alcohols:

$$CS{:}N.C_2H_5+C_2H_5.OH=C_2H_5NH.CS.OC_2H_5.$$

They are liquids with an odour like that of leeks, boil without decomposition and break up into alcohols, CO_2, H_2S, and alkylamines, and can easily be transformed by halogen alkyls into the isomeric thiolcarbamic esters (above) (C. 1899, II. 618). *Ethyl Thiocarbamic Ethyl Ester*, $C_2H_5.NHCSOC_2H_5$, m.p. 46°, b.p. 206°. *Allyl Thiocarbamic Ethyl Ester*, $C_3H_5.NHCSOC_2H_5$, is prepared from allyl mustard oil. *Acetyl Thiocarbamic Methyl Ester*, $CH_3CO.NHCS(OCH_3)$, m.p. 80°, is prepared from thiocarbamic ester and acetic anhydride; or from lead thiocyanate, acetyl chloride, and methyl alcohol. It is converted by iodomethane into the isomeric *Methyl Acetyl Thiolcarbamate*, $CH_3CO.NHCOSCH_3$, m.p. 146° (C. 1900, II. 853).

Dithiocarbamic Acid, $NH_2.CSSH$ or $NH=C(SH)_2$, is obtained as a red oil upon decomposing its ammonium salt with dilute sulphuric acid. It readily breaks down into thiocyanic acid, HS.NC, and hydrogen sulphide. Water decomposes it into cyanic acid and $2H_2S$. Its *ammonium salt*, $NH_2.CSSNH_4$, is formed when alcoholic ammonia acts on carbon disulphide. It consists of yellow needles or prisms.

Alkyl Dithiocarbamic Acids, *Dithiocarbalkylaminic Acids.* The amino-salts of these compounds are formed by heating together carbon disulphide and primary or secondary amines in alcoholic solution:

$$CS_2+2C_2H_5NH_2=C_2H_5NH.CSSNH_3C_2H_5.$$

When the amine salts of ethyl dithiocarbamic acid are heated to 110° dialkylated hio ureas are formed (p. 453):

$$C_2H_5NHCS.SH.NH_2C_2H_5=C_2H_5NHCSNHC_2H_5+H_2S.$$

f the salts formed with primary amines are heated in aqueous solution with netallic salts such as $AgNO_3$, $FeCl_3$, or $HgCl_2$, salts of ethyl dithiocarbamic acid re precipitated:

$$C_2H_5NHCSS(NH_3C_2H_5)\xrightarrow{AgNO_3}C_2H_5NHCSSAg+HNO_3.H_2NC_2H_5,$$

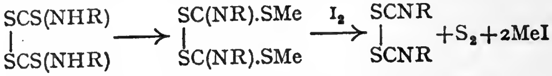
hich, when boiled with water, yield *mustard oil* or *isothiocyanic ester* (p. 469).

The *secondary amine* salts of *dithiocarbamic acid* give no mustard oil (B. **8**, 07).

Oxidation with iodine changes the mono- and di-alkyl dithiocarbamic acids to *thiuram disulphides*:

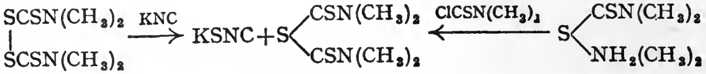
$$2RNHCS.SH\xrightarrow{I_2}\begin{array}{l}SCSNHR\\ \;|\\ SCSNHR.\end{array}$$

These disulphides, when possessing hydrogen atoms available for the reaction, are decomposed by heat partly into mustard oils, S and H_2S, and partly into dialkyl thioureas, S, and CS_2. Sodium alcoholate converts them into salts of the isomeric isothiuram disulphide. The latter are converted directly into mustard oil and sulphur by repeated treatment with iodine (B. **35**, 817).



$$\begin{array}{l}SCS(NHR)\\|\\SCS(NHR)\end{array}\longrightarrow\begin{array}{l}SC(NR).SMe\\|\\SC(NR).SMe\end{array}\xrightarrow{I_2}\begin{array}{l}SCNR\\|\\SCNR\end{array}+S_2+2MeI$$

If alkyl or acyl halides are employed instead of iodine, the decomposition results in mustard oil dialkyl disulphides, or diacyl disulphides (pp. 144, 274) (B. **36**, 2259). Tetra-alkyl thiuram disulphides and potassium cyanide yield the yellow coloured *thiuram monosulphide* and potassium thiocyanate. These are also obtained from dithiocarbamic salts with dithiocarbamic acid chlorides (see below (B. **36**, 2275):

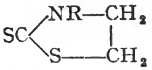


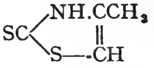
$$\begin{array}{l}SCSN(CH_3)_2\\|\\SCSN(CH_3)_2\end{array}\xrightarrow{KNC}KSNC+S\begin{array}{l}\diagup CSN(CH_3)_2\\\diagdown CSN(CH_3)_2\end{array}\xleftarrow{ClCSN(CH_3)_2}S\begin{array}{l}\diagup CSN(CH_3)_2\\\diagdown NH_2(CH_3)_2\end{array}$$

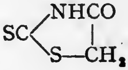
Dithiourethanes, *Dithiocarbamic Esters*, are obtained by several methods (B. **35**, 3368; C. 1903, I. 139). They are readily prepared (1) from ammonium dithiocarbamate (below) and iodoalkyls:

$$NH_2CSS.NH_4\xrightarrow{CH_3I}NH_2CSSCH_3;\ (CH_3)_2NCS_2NH_2(CH_3)_2\xrightarrow{CH_3I}(CH_3)_2NCS_2CH_3.$$

It must be noticed, however, that alkylene dihalides, α-halogen ketones, and α-halogen fatty esters convert the dithiocarbamates easily into cyclic *thiazole* derivatives:







(2) from chlorodithiocarbonic esters (p. 434) and amines:

$$C_2H_5SCSCl+NH(C_3H_7)_2\longrightarrow C_2H_5SCSN(C_3H_7)_2$$

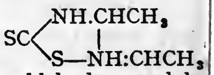
(3) from thiocyanic esters and H_2S:

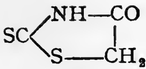
$$C_2H_5SC{:}N+H_2S\longrightarrow C_2H_5SCSNH_2.$$

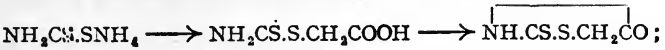
The dithiocarbodialkylamine acid esters are stable, whilst the simpler derivatives easily decompose into mercaptans and mustard oils or thiocyanic acid.

Dithiocarbamic Methyl Ester, $NH_2CS_2CH_3$, m.p. 41°; *ethyl ester*, m.p. 42°; *isopropyl ester*, m.p. 97°; *allyl ester*, m.p. 32°; *Methyl Dithiocarbamic Methyl Ester*, $CH_3NHCS_2CH_3$, b.p.$_{20}$ 156°. *Dimethyl Dithiocarbamic Methyl Ester*, $(CH_3)_2NCS_2CH_3$, m.p. 47°. Excess of iodo-alkyl converts the dithio- and alkyl dithio-carbamic esters into the *hydroiodides* of *imidodithiocarbonic esters*, $HN.C(SCH_3).RN{:}C(SC_2H_5)_2$, which, on hydrolysis, yield dithiocarbonic esters (p. 432). *Acetyl Dithiourethane*, $CH_3CONHCS_2R$, is produced from acylation of dithiourethane, and from mustard oil by means of thioacetic acid (p. 273). They are converted by sodium alcoholate and iodo-alkyls into *Acetyl Imidodithiocarbonic Ester*, $CH_3CONC(SR)_2$ (C. 1901, II. 764; 1903, I. 446).

Dialkyl Thiocarbamic Acid Chloride, NR_2CSCl, is formed from thiophosgene and amines (B. **36**, 2274).

Cyclic Derivatives of Dithiocarbamic Acid.—*Carbothialdine,*  is obtained by heating ammonium dithiocarbamate with aldehyde; and by mixing CS_2 with alcoholic aldehyde-ammonia. It forms large shining crystals Isomeric with this is *Dimethyl Formocarbothialdine*, $CS_2(NCH_3)_2(CH_2)_2$, which is prepared from CS_2 and formaldehyde-methylimide. Iodomethane breaks i down into *Methylimidodithiocarbonic Dimethyl Ester*, $CH_3N{:}C(SCH_3)_2$ (see above (C. 1896, II. 478).

Rhodanic acid, , m.p. 169°, with decomposition, is prepared from ammonium dithiocarbamate with salts or esters of chlor- or thio-acetic acid:



$$NH_2CS.SNH_4 \longrightarrow NH_2CS.S.CH_2COOH \longrightarrow NH.CS.S.CH_2CO;$$

the homologous α-halogen fatty acids behave similarly. Mustard oils (p. 469) and thioacetic acid form *n*-alkyl rhodanic acids. Rhodanic acid condenses with aromatic aldehydes, eliminating water and forming dyes: $ArCH:(C_3S_2NOH)$ (C. 1903, I. 446; II. 836; 1906, I. 1436; B. **39**, 3068).

Thiourea, Sulphourea, Sulphocarbamide, $CS{<}\genfrac{}{}{0pt}{}{NH_2}{NH_2}$, or $NH{:}C{<}\genfrac{}{}{0pt}{}{NH_2}{SH}$, m.p. 172°, is obtained (as first observed by *Reynolds* in 1869—A. **150**, 224) by heating ammonium thiocyanate to 170–180° (A. **179**, 113), when a transposition analogous to that occurring in the formation of urea takes place (p. 438). This synthesis, however, does not proceed with ease, and is never complete, because at 160–170° sulphourea is again changed to ammonium thiocyanate:

$$CSN.NH_4 \xrightarrow{180^\circ} CS(NH_2)_2.$$

Sulphourea is also produced by the action of hydrogen sulphide (in presence of a little ammonia) or ammonium thiocyanate on cyanamide (B. **8**, 26):

$$CNNH_2+SH_2=CS(NH_2)_2.$$

Sulphocarbamide crystallizes in thick, rhombic prisms, which dissolve easily in water and alcohol, but with difficulty in ether; they possess a bitter taste and have a neutral reaction.

Reactions: (1) When sulphocarbamide is heated with water to 140° it again becomes ammonium thiocyanate. (2) If boiled with alkalis, hydrochloric acid or sulphuric acid, it decomposes according to the equation:

$$CSN_2H_4+2H_2O=CO_2+2NH_3+H_2S.$$

(3) Silver, mercury, or lead oxide and water will convert it, at ordinary temperatures, into cyanamide, CN_2H_2; and on boiling into dicyandiamide (p. 457). (4) $KMnO_4$ changes it, in cold aqueous solution, into urea. (5) In nitric acid solution, or by means of H_2O_2 in oxalic acid solution, salts of a disulphide, $NH_2.C{=}(NH)S{-}S(NH){=}C.NH_2$, not known in a free state, are produced (B. **24**, R. 71). (See B. **25**, R. 676, upon the condensation of thiourea with aldehyde-ammonias.) Sulphourea condenses with α-chloraldehydes and α-chloroketones to *amidothiazoles* (Vol. II.). It yields *aromatic glyoxaline* (Vol. II.) derivatives when heated with benzoïn.

Constitution.—The behaviour of thiourea when oxidized in acid solution, and certain other reactions, rather support the formula $NH{:}C{<}\genfrac{}{}{0pt}{}{NH_2}{SH}$ instead of the diamide formula (comp. J. pr. Ch. [2] **47**, 135). Possibly free thiourea possesses the symmetrical formula, whilst its salts are derived from the *pseudo-form* $NH{:}C{<}\genfrac{}{}{0pt}{}{NH_2}{SH}$ (p. 448).

Thiourea combines with 1 equivalent of acid to form salts. The *nitrate*, $CSN_2H_4.HNO_3$, occurs in large crystals; *hydrochloride*, see C. 1902, I. 113. Auric chloride and platinic chloride throw down red-coloured double chlorides from the concentrated solution. Silver nitrate precipitates $CSN_2H_4.AgNO_3$ (B. **24**, 3956; B. **25**, R. 583) For the constitution of these metallic salts see B. **17**, 297. For the compounds of cuprous chloride with 1, 2, or 3 molecules of thiourea, to form "co-ordinated complex salts," see A. **349**, 232.

Alkyl Sulphocarbamides, in which the alkyl groups are linked to nitrogen, are produced—

(1) On heating the mustard oils with primary and secondary amine bases (*A. W. Hofmann*, B. **1**, 27):

$$NH_3+CS:N.C_2H_5=NH_2.CS.NHC_2H_5.$$

Ethyl Sulphocarbamide.

$$NH_2.C_2H_5+CS:N.C_2H_5=NHC_2H_5CSNHC_2H_5.$$

sym. Diethyl Sulphocarbamide.

$$NH(C_2H_5)_2+CS:N.C_2H_5=N(C_2H_5)_2CSNHC_2H_5.$$

Triethyl Sulphocarbamide.

(2) By heating the amine salts of the alkyl dithiocarbamic acids (B. **1**, 25) (p. 450):

$$C_2H_5NHCS.SNH_3C_2H_5=C_2H_5NHCSNHC_2H_5+H_2S.$$

(3) By heating the corresponding aminothiocyanates (B. **24**, 2724; **26**, 2497).

Ethyl Sulphocarbamide, $NH_2CSNH.C_2H_5$, m.p. 113°, dissolves readily in water and alcohol.

sym.-*Diethyl Sulphocarbamide*, $CS(NH.C_2H_5)_2$, m.p. 77°. *Triethyl Thiourea*, m.p. 26°, b.p. 205°. *Monomethyl Thiourea*, m.p. 119°. sym.-*Dimethyl Thiourea*, m.p. 61° (B. **24**, 2729; **28**, R. 424). unsym.-*Dimethyl Thiourea*, $NH_2CSN(CH_3)_2$, m.p. 159° (B. **26**, 2505). *Propyl Thiourea*, see B. **23**, 286; **26**, R. 87.

Allyl Sulphocarbamide, Thiosinamine, $NH_2CSNH.C_3H_5$, m.p. 74°, is formed by the union of allyl mustard oil with ammonia (p. 469).

It is readily soluble in water, alcohol, and ether. Allyl cyanamide sinamine and triallyl melamine are produced on boiling with mercuric oxide or lead hydroxide (p. 472). Hydrogen bromide changes it to propylene ψ-thiourea (comp. **20**, R. 684).

Diallyl Sulphocarbamide, m.p. 49°, is prepared from allyl mustard oil and allylamine (C. 1898, II. 768).

Reactions of the Alkyl Sulphoureas.

(1) The sulphocarbamides regenerate amines and mustard oils by distillation with P_2O_5, or when heated in HCl-gas:

$$C_2H_5.NHCSNHC_2H_5=C_2H_5N:C:S+NH_2C_2H_5.$$

(2) The sulphur in the alkyl sulphocarbamides will be replaced by oxygen if these compounds are boiled with water and mercuric oxide or lead oxide. (*a*) Those that contain two alkyl groups yield the corresponding ureas:

$$(C_2H_5NH)_2CS+HgO=(C_2H_5NH)_2CO+HgS;$$

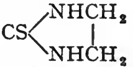
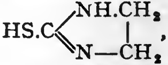
whereas (*b*) the mono-derivatives pass into alkylic cyanamides (and melamines) after parting with hydrogen sulphide (pp. 472, 473).

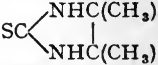
$$C_2H_5NHCSNH_2=C_2H_5NHC\vdots N+H_2S.$$

(3) On digesting the dialkyl sulphocarbamides with mercuric oxide and amines, sulphur is exchanged for the imid-group and *guanidine* derivatives appear (p. 455):

$$(C_2H_5NH)_2CS+NH_2C_2H_5+HgO=(C_2H_5NH)_2C:NC_2H_5+HgS+H_2O.$$

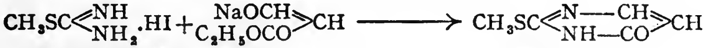
Consult B. **23**, 271, upon the constitution of the dialkyl sulphocarbamides.

Ethylene Sulphocarbamide,  $CS\left\langle\begin{array}{l}NHCH_2\\ \quad\;|\\ NHCH_2\end{array}\right.$ or  $HS.C\left\langle\begin{array}{l}NH.CH_2\\ \quad\;\;|\\ N—CH_2\end{array}\right.$, m.p. 195°, is obtained from ethylene diamine and carbon disulphide (B. **5**, 242).

Pinacolyl Sulphocarbamide, Carbothiacetonine,  $SC\left\langle\begin{array}{l}NHC(CH_3)_2\\ \quad\;\;|\\ NHC(CH_3)_2\end{array}\right.$, m.p. 240–243°, is formed by the action of ammonia on carbon disulphide and acetone (B. **29**, R. 669).

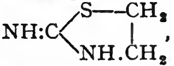
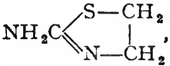
Derivatives of Pseudosulphocarbamide.—In the preceding derivatives—whether they are derived from the sym.- or unsym.- sulphocarbamide formula or not—the alkyl groups were in all cases joined to nitrogen, whereas the compounds about to be described must be considered as derivatives of pseudosulphocarbamide,

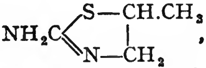
The *alkyl pseudosulphocarbamides* result upon the addition of alkyl iodides to the thioureas. The alkyl groups contained in them are known to be united with sulphur because, when they are acted on with ammonia, they are changed to guanidines and mercaptans. They also easily condense, like the ψ-urea ethers (p. 446) with β-aldo- and β-keto-carboxylic esters into the cyclic derivatives and mercaptopyrimidines, which are hydrolyzed into mercaptans and pyrimidines (B. **11**, 492; **23**, 2195; C. 1903, I. 1308; 1905, I. 1710):

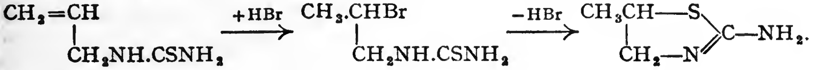


ψ-Methyl Thiourea Iodide. Sodium Formyl Acetic Ester. Methyl Mercapto-oxypyrimidine.

Alkylene Derivatives of Pseudosulphourea.

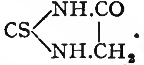
Ethylene Pseudothiourea, , or , m.p. 85°, is obtained from bromethylamine hydrobromide and potassium thiocyanate. It is a base with strong basic properties, and its salts crystallize well (B. **22**, 1141, 2984; **24**, 260).

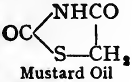
Propylene Pseudothiourea, , formed from bromopropylamine and potassium thiocyanate, is perfectly similar. It also results from allyl-thiourea by action of hydrobromic acid (p. 452):



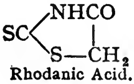
Acetyl Pseudothiourea,  $NH{:}C<^{NH_2}_{SCO.CH_3}$, m.p. 165°, is obtained from thiourea by heating it with acetic anhydride; also from cyanamide (carbodiimide, p. 471) and *thioacetic acid.* This second method argues for the compound being a derivative of pseudosulphocarbamide.

Carboxalkyl Sulphocarbamide, Thio- or *ψ-Thio-allophanic Ester,* $ROOC.NHCSNH_2$ or $ROOC.SC(NH)NH_2$, is produced by the addition of ammonia or amines to the *carboxalkyl thiocarbimides* (p. 471) (C. 1901, II. 211), and by the interaction of chlorocarbonic esters on thiourea (C. 1903, I. 1123). *Dithiobiuret,* $R_2NCS.NR.CSNR_2$, and *ψ-Dithiobiuret,* $R_2NC(NR)S.CSNR_2$ (B. **37**, 4317).

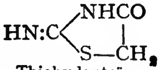
Pseudothio- or -sulpho-hydantoïn, $C_3H_4N_2S$ (below), is obtained when chloracetic acid (A. **166**, 383; B. **31**, 137) acts on sulphocarbamide, and was formerly thought to be the real thiohydantoïn, . However, its formation from cyanamide and thioglycollic acid (p. 376) and its decomposition, when boiled with barium hydroxide solution, into thioglycollic acid and dicyandiamide prove that it is a pseudosulphocarbamide derivative, which contains the ring occurring in thiazole compounds (B. **12**, 1385, 1588). Similar thiazole derivatives result when monochloracetic acid is replaced by α-bromopropionic acid, bromomaleïc acid, and other halogen-carboxylic acids; also when unsaturated acids are employed, such as citraconic acid, to react with thiourea (C. 1897, I. 853). Pseudosulphohydantoïn crystallizes in long needles, which decompose at about 200°. When boiled with acids, it loses ammonia and is changed into *mustard oil acetic acid* (p. 469). It is closely related to rhodanic acid (p. 451):



Mustard Oil Acetic Acid.



Rhodanic Acid.



Thiohydantoïn.

Alkyl Hydroxythioureas are formed by the action of an ethereal solution of anhydrous hydroxylamine and β-alkyl hydroxylamines on mustard oil in ether. The monoalkyl hydroxythioureas readily decompose into sulphur and alkyl ureas (comp. on the contrary phenyl hydroxythiourea (Vol. II.)); the dialkyl hydroxythioureas are stable. *Ethyl Hydroxythiourea*, $C_2H_5NH.CSNOH$, m.p. 109°; sym.-*Diethyl Hydroxythiourea*, $C_2H_5NH.CS.NC_2H_5)OH$, m.p. 81° (A. **298**, 117).

Hydrazine Derivatives of Thiocarbonic Acid.

Dithiocarbazine Acid Hydrazine Salt, $NH_2NH.CS.SNH_2.NH_2$, m.p. 124°, is formed by the interaction of hydrazine hydrate and CS_2 (B. **29**, R. 233). *α-Carbamyl β-Thiocarbamyl Hydrazine*, $H_2N.CSNH.NHCONH_2$, m.p. 218–220° with decomposition, is formed from thiosemicarbazide hydrochloride and potassium cyanate (B. **29**, 2508). Boiling concentrated hydrochloric acid converts it into *thiourazole*, $\begin{matrix}NHCS\\NHCO\end{matrix}{>}NH$, m.p. 177°. *αβ-Dithiocarbamyl Hydrazine*, $NH_2CSNH.NHCSNH_2$, m.p. 214°, results when a solution of hydrazine sulphate and ammonia thiocyanate is boiled (B. **26**, 2877).

Thiosemicarbazide, $\overset{1}{N}H_2.\overset{2}{N}H\overset{3}{C}S\overset{4}{N}H_3$, m.p. 181°, is formed together with αβ-dithiocarbamyl hydrazine (see above), when hydrazine sulphate and ammonium thiocyanate are boiled together in solution. Like semicarbazide (p. 466) it readily reacts with aldehydes and ketones to form *thiosemicarbazones*, $RCH{:}NNHCSNH_2$, $R_2C{:}NHNCSNH_2$. They are particularly suitable for isolating aldehydes and ketones on account of the insoluble precipitates given with silver mercury, and copper salts (B. **35**, 2049). 4-*Methyl Thiosemicarbazide*, $CH_3NH.CSNHNH_2$, m.p. 137°; 2,4-*Dimethyl Thiosemicarbazide*, $CH_3NH.CSN(CH_3)NH_2$, m.p. 138°, and 2,4-*Methyl Allyl Thiosemicarbazide*, m.p. 57°, are prepared from hydrazine and methyl hydrazine with methyl and allyl mustard oil respectively. They combine readily with aldehydes (B. **37**, 2320). *αβ-Dithiocarbamyl Diallylamine*, $C_3H_5NH.CSNH.NH.CSNHC_3H_5$ (B. **29**, 859). *Formyl Methyl Thiosemicarbazide*, m.p. 167°, yields, with acetyl chloride *methylimidothiobiazoline*, m.p. 245° (B. **27**, 622):

$$\begin{matrix}NH—NH\\ |\qquad\quad |\\ CH_3NHCS\quad CHO\end{matrix} \longrightarrow \begin{matrix}NH—N\\ |\qquad \|\\ CH_3N{:}C—S—CH.\end{matrix}$$

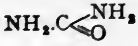
Dithiourazole, $\begin{matrix}NH—CS\\ |\qquad\quad\\ NH—CS\end{matrix}{>}NH$, m.p. about 245° with decomposition, is formed on heating αβ-dithiocarbamyl hydrazine with hydrochloric acid. The hydrochloride of imidothiourazole, $\begin{matrix}NH.CS—\\ |\qquad\quad\\ NH.C(NH)\end{matrix}{>}NH$, is produced at the same time (B. **28**, 949).

Appendix. *Potassium Diazomethane Disulphonate*, $N_2C(SO_3K)_2$, orange-yellow needles, is prepared from *Potassium Aminomethane Disulphonate*, $NH_2CH(SO_3K)_2$, the addition product of potassium cyanide and two molecules of potassium bisulphite, by means of nitrous acid. With iodine it yields *potassium di-iodomethane disulphonate*, $I_2C(SO_3K)_2$; and is converted by heat into *Potassium Azinomethane Disulphonate*, $(SO_3K)_2C{:}N.N{:}C(SO_3K)_2$, in the form of colourless crystals. The action of diazobenzene (Vol. II.) on the potassium bisulphite compound with potassium diazomethane disulphonate produces *Potassium Methane Disulphonate Phenylhydrazone*, $C_6H_5.NHN{:}C(SO_3K)_2$ and ulitmately *Formazyl Sulphonic Acid*, $\begin{matrix}C_6H_5N{:}N\\C_6H_5NHN\end{matrix}{\geqslant}CSO_3H$ (B. **29**, 2161).

GUANIDINE AND ITS DERIVATIVES

Guanidine is, upon the one hand, very closely related to orthocarbonic ester, urea and sulphocarbamide, and, upon the other, to cyanamide (p. 426), and all are inter-connected by a series of reactions.

Guanidine belongs to the amidines, and may be regarded as the amidine of amidocarbamic acid:


$NH_2.C\left\langle\begin{array}{l}NH_2\\ O\end{array}\right.$

Urea.


$NH_2.C\left\langle\begin{array}{l}NH_2\\ S\end{array}\right.$

Sulphocarbamide.


$NH_2C\left\langle\begin{array}{l}NH_2\\ NH\end{array}\right.$

Guanidine.

The pseudo-forms of urea and thiourea—


$HO.C\left\langle\begin{array}{l}NH_2\\ NH\end{array}\right.$

(Pseudourea).


$HS.C\left\langle\begin{array}{l}NH_2\\ NH\end{array}\right.$

(Pseudosulphourea).

known in the form of various derivatives, are the amidines of carbonic and thiocarbonic acids.

Guanidine, $HN{:}C(NH_2)_2$, was first obtained (*A. Strecker*, 1861) by the oxidation of guanine (a substance closely related to uric acid, and found in guano) with hydrochloric acid and potassium chlorate. It is found in vetch seeds and in beet-juice (B. **29**, 2651). It is also important as the substance from which creatine is derived. It is formed synthetically (1) by heating cyanogen iodide and NH_3, and from cyanamide (p. 471) and ammonium chloride in alcoholic solution at 100°:

$$NH_2.C{\equiv}N+NH_3.HCl=(H_2N)_2C{:}NH.HCl.$$

This is analogous to the formation of formamidine from hydrocyanic acid. (2) It is also produced by heating chloropicrin or (3) esters of orthocarbonic acid, with aqueous ammonia:

$$CCl_3(NO_2)+3NH_3=(H_2N)_2C{:}NH+3HCl+HNO_2$$
$$C(OC_2H_5)_4+3NH_3=(H_2N)_2C{:}NH+4C_2H_5OH.$$

(4) It is most readily prepared from the thiocyanate, which is made by prolonged heating of ammonium thiocyanate to 180–190°, and the further transposition of the thiourea that first forms (B. **7**, 92):

$$2NH_4SNC=2(H_2N)_2CS=(H_2N)_2C{:}NH.CNSH+H_2S.$$

The crystals of guanidine are very soluble in water and alcohol, and deliquesce on exposure. Barium hydroxide solution changes it to urea. Guanidine salts of the fatty acids are converted by heat into *guanamines*, which will be described with the cyanuric compounds (p. 474).

Salts.—It is a strong base, absorbing CO_2 from the air and yielding crystalline salts with 1 equivalent of the acids. The *nitrate*, $CN_3H_5.HNO_3$, consists of large scales, which are sparingly soluble in water; *hydrochloride*, $CN_3H_5.HCl_3$, yields a platinum double salt, crystallizing in yellow needles; *carbonate*, $(CN_3H_5)_2.H_2CO_3$, consists of quadratic prisms, and reacts alkaline (see C. 1907, I. 153); *thiocyanate*, $CN_3H_5.HSCN$, crystallizes in large leaflets, m.p. 118°. *Silver guanidine*, $CN_3Ag_2H_3+H_2O$ (A. **302**, 33).

The **alkyl guanidines** result (1) on heating cyanamide with the HCl-salts of the primary amines—*e.g.* $CH_3NH_2.HCl$, forming *Methyl Guanidine;* (2) by boiling sym.-dialkyl thioureas (p. 452) with mercuric oxide and ethylamine in alcoholic solution (B. **2**, 601), producing *Triethyl Guanidine.*

Vice versâ, the alkylated guanidines, when heated with CS_2, have their imide-group replaced by sulphur, with formation of thioureas (p. 451).

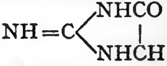
Acyl Guanidines are formed when guanidine hydrochloride is heated with acid chlorides under pressure (C. 1903, II. 988).

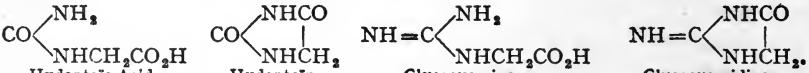
Guaneïdes of the Hydroxyacids.—The guanidine derivatives corresponding with the ureïdes of glycollic acid, hydantoïc acid, and hydantoïn are known. Creatine and creatinine, important from a physiological standpoint, belong to this class.

Glycocyamine, Guanidine Acetic Acid, $\mathrm{NH{=}C{<}^{NH_2}_{NHCH_2CO_2H}}$, is obtained by the direct union of glycocoll with cyanamide; or by heating guanidine carbonate with glycocoll (C. 1905, I. 156):

$$NH_2(NH)CNH_2+NH_2CH_2COOH=NH_2(NH)CNHCH_2COOH+NH_3.$$

It dissolves with difficulty in cold water and rather readily in hot water, whilst it is insoluble in alcohol and ether. It forms salts with acids and bases. When heated it becomes carbonized without melting.

Glycocyamidine, Glycolyl Guanidine,  $\mathrm{NH{=}C}{<}\begin{matrix}\mathrm{NHCO}\\ |\\ \mathrm{NHCH_2}\end{matrix}$, bears the same relation to glycocyamine as hydantoïn to hydantoïc acid:



$\mathrm{CO{<}^{NH_2}_{NHCH_2CO_2H}}$ Hydantoïc Acid. $\mathrm{CO}{<}\begin{matrix}\mathrm{NHCO}\\ |\\ \mathrm{NHCH_2}\end{matrix}$ Hydantoïn. $\mathrm{NH{=}C{<}^{NH_2}_{NHCH_2CO_2H}}$ Glycocyamine. $\mathrm{NH{=}C}{<}\begin{matrix}\mathrm{NHCO}\\ |\\ \mathrm{NHCH_2}\end{matrix}.$ Glycocyamidine.

It is produced when glycocyamine hydrochloride is heated to 160°.

Creatine, *Methyl Glycocyamine, Methyl Guanidine Acetic Acid,* $\mathrm{NH{:}C{<}^{NH_2}_{N(CH_3)CH_2CO_2H}}$, was first discovered in 1834 by *Chevreul* in meat extract (κρέας, flesh). *Liebig* (1847) gave it a thorough investigation in his classic research entitled "Ueber die Bestandtheile der Flüssigkeiten des Fleisches" (A. **62**, 257). It is found especially in the fluids of muscles. It may be artificially prepared (*J. Volhard,* 1869), like glycocyamine, by the union of *sarcosine* (methyl glycocoll) with cyanamide:

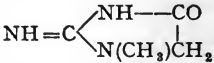
$$CN.NH_2+NH(CH_3).CH_2CO_2H=H_2N(NH)C.N(CH_3).CH_2COOH.$$

Creatine crystallizes with one molecule of water in glistening prisms. Heated to 100°, they lose of water. It reacts neutral, and has a faintly bitter taste. It dissolves rather readily in boiling water, but with difficulty in alcohol; and yields crystalline salts with one equivalent of acid.

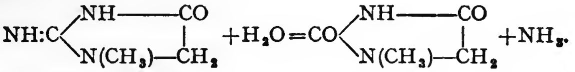
(1) When digested with acids, creatine loses water and becomes changed into creatinine (see below), and (2) with barium hydroxide solution it is converted into urea and sarcosine:

$$\mathrm{NH{:}C{<}^{NH_2}_{N(CH_3).CH_2CO_2H}+H_2O=CO{<}^{NH_2}_{NH_2}+NH(CH_3)CH_2CO_2H.}$$

Ammonia is liberated at the same time, and β-methyl hydantoïn is formed. (3) When its aqueous solution is heated with mercuric oxide, creatine yields oxalic acid and methyl guanidine. (4) With acetic anhydride it yields *Diacetyl Creatine,* m.p. 165° (A. **284**, 51).

Creatinine, *Methyl Glycocyamidine,*  $\mathrm{NH{=}C}{<}\begin{matrix}\mathrm{NH{-}{-}CO}\\ |\\ \mathrm{N(CH_3)CH_2}\end{matrix}$, occurs constantly in urine (about 0·25 per cent.), and is readily obtained from creatine by evaporating its aqueous solution, especially when acids are present. It crystallizes in rhombic prisms, and is much more soluble than creatine, in water and alcohol. It is a strong base, which can expel ammonia from ammonium salts and yields well-crystallized salts with acids. Its compound with zinc chloride $(C_4H_7N_3O)_2.ZnCl_2$, is particularly characteristic. Zinc chloride precipitates it from creatinine solutions as a crystalline powder, dissolving with difficulty in water.

(1) Bases cause creatinine to absorb water and become creatine again. (2) Boiled with barium hydroxide solution it decomposes into β-methyl hydantoïn and ammonia:



$$NH:C{<}\begin{matrix}NH-CO\\N(CH_3)-CH_2\end{matrix} + H_2O = CO{<}\begin{matrix}NH-CO\\N(CH_3)-CH_2\end{matrix} + NH_3.$$

(3) When boiled with mercuric oxide it breaks up like creatine into methyl guanidine and oxalic acid.

When creatinine is heated with alcoholic ethyl iodide, the *ammonium iodide of ethyl creatinine*, $C_4H_7(C_2H_5)N_3O.I$, is produced. Silver oxide converts this into the ammonium base, $C_4H_7(C_2H_5),N_3O.OH$.

α-Guanidine Propionic Acid, $(N_2H_3)C.NH.CH(CH_3)COOH$, m.p. 180°. *β-Guanidine Propionic Acid*, m.p. 206–213°, with decomposition, when heated with hydrochloric acid yields the hydrochloride of *β-alacreatinine*, $HN:\overline{CNHCH_2CH_2CONH}$ (C. 1905, I. 156).

Guaneïdes of Carbonic Acid.—Guanoline, guanyl urea, biguanide, and probably dicyandiamide, corresponding with allophanic ester, biuret, and cyanurea, (p. 455), are derivatives of the guaneïde of carbonic acid. This is not known, and probably cannot exist:

$CO{<}\begin{matrix}NH_2\\NHCO_2C_2H_5\end{matrix}$

Allophanic Ester.

$CO{<}\begin{matrix}NH_2\\NHCONH_2\end{matrix}$

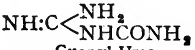
Biuret.

$CO{<}\begin{matrix}NH_2\\NHCN\end{matrix}$

Cyanurea.

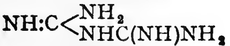
$NH:C{<}\begin{matrix}NH_2\\NHCO_2C_2H_5\end{matrix}$

Guanoline.



$NH:C{<}\begin{matrix}NH_2\\NHCONH_2\end{matrix}$

Guanyl Urea.



$NH:C{<}\begin{matrix}NH_2\\NHC(NH)NH_2\end{matrix}$

Biguanide.

$NH:C{<}\begin{matrix}NH_2\\NH.CH.\end{matrix}$

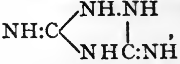
Dicyandiamide (?).

Guanoline, *Guanidocarbonic Ester*, $NH:C{<}\begin{matrix}NH_2\\NHCO_2C_2H_5\end{matrix} + \frac{1}{2}H_2O$, m.p., dehydrated, 114°. It is obtained from *Guanidodicarbonic Diethyl Ester*, $NH:C(NH.CO_2C_2H_5)_2$, the reaction-product arising from chlorocarbonic ester and guanidine, through the action of ammonia (B. **7**, 1588).

Dicyandiamidine, *Guanyl Urea*, $NH:C{<}\begin{matrix}NH_2\\NH.CO.NH_2\end{matrix}$, is formed (1) by the action of dilute acids on dicyandiamide or cyanamide, or (2) by fusing a guanidine salt with urea (B. **7**, 446), (3) from urea by heating it with benzene sulphochloride, whereby it is obtained as a benzene sulphonate (C. 1901, I. 885). It is a strongly basic, crystalline substance. It forms a copper derivative having a characteristic red colour, and a yellow nickel compound, $Me(N_4H_5OC_2)_2+H_2O$ (B. **39**, 3356). When digested with barium hydroxide solution it decomposes into CO_2, $2NH_3$, and urea (B. **20**, 68).

Biguanide, *Guanyl Guanidine*, $NH:C{<}\begin{matrix}NH_2\\NHC(NH)NH_2\end{matrix}$, is formed (1) on heating guanidine hydrochloride to 180–185°; (2) when cyanoguanidine is heated with ammonium chloride. It is a strongly alkaline base, forming a copper derivative with characteristic red colour. Chloroform and alkali hydroxide convert it into *formoguanamine* (p. 474).

Dicyandiamide, *Param*, *Cyanoguanidine*, $NH:C{<}\begin{matrix}NH_2\\NH.CN\end{matrix}$, m.p. 205°, results from the polymerization of cyanamide upon long standing or by evaporation of its aqueous solution, and can easily be prepared from technical calcium or sodium cyanamide (p. 471) (C. 1905, II. 1530, etc). Contrary to the two substances described above, it is a neutral body. Ammonia converts it into biguanide; dilute acids into guanyl urea. With piperidine it forms a *biguanide derivative* (B. **24**, 899; **25**, 525), with hydrazine hydrochloride when heated in alcoholic solution it gives *guanazole*,



$NH{:}C\langle\begin{smallmatrix}NH.NH\\ |\\ NHC{:}NH\end{smallmatrix}$, m.p. 206° (B. **27**, R. 583); both reactions form a basis for the ascribed formula.

Thiocyanodiamidine, *Guanyl Thiourea,* $NH_2CSNHC(NH)NH_2$, is obtained from thiourea and PCl_5 or thiophosgene. It is isomerized at 100° to guanidine thiocyanate. Silver salts produce dicyanodiamide with loss of H_2S (comp. B. **36**, 3322).

Nitro-, amino-, and Hydroxy-guanidines and their transposition products.

Of these substances, nitroguanidine is the most suitable material for the preparation of a series of remarkable guanidine and urea derivatives (*Thiele,* A. **270**, 1; **273**, 133; B. **26**, 2598, 2645).

Nitroguanidine, $NH{:}C{<}\begin{smallmatrix}NHNO_2\\ NH_2\end{smallmatrix}$, m.p. 230°, results on treating guanidine with a mixture of nitric and sulphuric acids. It dissolves with difficulty in cold water, more readily in hot water, and particularly freely in alkalis, because of its feeble acid character.

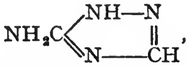
Nitrosoguanidine, $NH{:}C{<}\begin{smallmatrix}NH.NO\\ NH_2\end{smallmatrix}$ (?), is produced by reducing nitroguanidine with zinc dust and sulphuric acid. It consists of yellow needles, which explode at 160–165°.

Aminoguanidine, $NH{:}C{<}\begin{smallmatrix}NHNH_2\\ NH_2\end{smallmatrix}$, results when nitro- and nitrosoguanidine are reduced with zinc dust and acetic acid, or by electrolysis in neutral solution with a zinc cathode (C. 1906, I. 1066), and can be precipitated as a slightly soluble bicarbonate (A. **302**, 333). Aminoguanidine decomposes readily when in a pure condition, and when boiled with acids it breaks down, with the temporary production of semicarbazide (p. 446), into carbonic acid, ammonia, and *hydrazine,* which can therefore be conveniently prepared in this manner:

$$NH{:}C{<}\begin{smallmatrix}NHNH_2\\ NH_2\end{smallmatrix} \xrightarrow{H_2O} CO{<}\begin{smallmatrix}NHNH_2\\ NH_2\end{smallmatrix} \xrightarrow{\quad H_2O\quad} CO_2+\begin{smallmatrix}NH_2NH_2\\ NH_3\end{smallmatrix}$$

Aminoguanidine forms well-crystallized compounds with dextrose, galactose, and lactose and many other aldehydes and ketones (B. **28**, 2613). Glyoxal and α-diketones with aminoguanidine lose water and form *bis-aminoguanidine* (A. **302**, 275).

Aminotriazole,

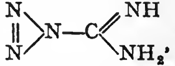


$NH_2C\langle\begin{smallmatrix}NH—N\\ \|\\ N——CH\end{smallmatrix}$, m.p. 159°, is formed from formyl aminoguanidine nitrate and soda (A. **303**, 33). See also *Guanazole* (above).

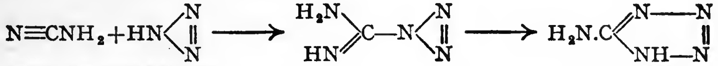
Azodicarbondiamidine, $\begin{smallmatrix}NH_2\\ HN\end{smallmatrix}{>}C—N{=}N—C{<}\begin{smallmatrix}NH_2\\ NH\end{smallmatrix}$, is obtained as nitrate when aminoguanidine nitrate is oxidized with $KMnO_4$. The azonitrate forms a yellow, sparingly soluble, crystalline powder, which explodes at 180–184°. It passes into azodicarbonamide (p. 447) when boiled with water.

Hydrazodicarbonamidine, $\begin{smallmatrix}NH_2\\ NH\end{smallmatrix}{>}C—NH—NH—C{<}\begin{smallmatrix}NH_2\\ NH\end{smallmatrix}$, results as nitrate when azodicarbonamidine nitrate is reduced with H_2S.

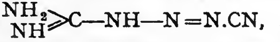
Azidocarbamidine, Carbamide Imidazide,

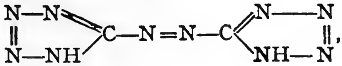


$\begin{smallmatrix}N\\ \|\\ N\end{smallmatrix}{>}N—C\langle\begin{smallmatrix}NH\\ NH_2\end{smallmatrix}$, corresponds with carbamic acid azide (p. 447). It is only stable in solution, since it very readily isomerizes into amidotetrazole (see below): *nitrate,* $(CN_5H_3)HNO_3$, m.p. 129°, is obtained from aminoguanidine and potassium nitrite in nitric acid solution, in the form of colourless crystals. Excess of sodium hydroxide solution converts it partially into *cyanamide* and *hydrazoic acid.* These substances unite in aqueous solution probably to reform azidocarbamidine, which is simultaneously isomerized to aminotetrazole (A. **314**, 339):

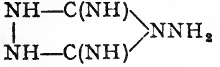


Cyanamide Hydrazoic Acid. Aminotetrazole.

Diazoguanidine Cyamide, Triazene Dicarboxylic Amide, Amino-imino-methyl Cyanotriazene,  $\genfrac{}{}{0pt}{}{NH_2}{NH}\!\!>\!C{-}NH{-}N{=}N.CN$, is produced from azidocarbamidine nitrate and potassium cyanide. The *amide*, obtained from the nitrile, takes up bisulphite and forms a *triazan-* or *prozan-* derivative—*Sodium Triazandicarboxylic Amidine Amidosulphonate,*  $\genfrac{}{}{0pt}{}{NH_2}{NH}\!\!>\!C.NH.N\!<\!\genfrac{}{}{0pt}{}{NHCONH_2}{SO_3Na}$ (A. **305**, 64, 80).

Azotetrazole,  results when amidotetrazole is oxidized by potassium permanganate (A. **303**, 57).

Isocyanotetrabromide or *Tetrabromoformalazine*, $Br_2C{=}N{-}N{=}CBr_2$, m.p. 42°, is produced when hydrazotetrazole, the reduction-product of azotetrazole, is treated with bromine (B. **26**, 2645). With alkalis isocyanotetrabromide apparently yields *isocyanoxide*, $CO{=}N{-}N{=}CO$ (?), or a polymer of it. Should an oxidizable body like alcohol be present, isocyanogen, $C{=}N{-}N{=}C$(?), is produced. This substance has an odour very much like that of isonitrile. Sodium ethoxide converts isocyanotetrabromide into *Azimethyl Carbonate*, $(CH_3O)_2C{=}N{-}N{=}C(OCH_3)_2$ (A. **303**, 71).

Diaminoguanidine, $HN{:}C(NHNH_2)_2$, obtained as a hydrochloride or hydrobromide by the action of cyanogen chloride or bromide on hydrazine. *Dibenzaldiaminoguanidine*, $HN{:}C(NHN{:}CHC_6H_5)_2$, m.p. 180°, exists as yellow needles. Hydrazine and two molecules of cyanogen bromide form *guanazine*, $HN{:}C(NHNH)_2C{:}NH$, or  (B. **37**, 4524; C. 1905, II. 122).

Triaminoguanidine, $H_2N.N{:}C(NHNH_2)_2$; its hydrochloride is obtained by heating hydrazine hydrate with carbon tetrachloride in a stream of ammonia. *Tribenzal Triaminoguanidine*, $C_6H_5CH{:}NN{:}C(NHN{:}CHC_6H_5)_2$, m.p. 196°, is hydrolyzed into benzaldehyde, hydrazine, and carbohydrazide (p. 447) (B. **37**, 3548).

Dihydroxyguanidine,  $H_2NC\!<\!\genfrac{}{}{0pt}{}{NOH}{NHOH}$, is obtained as hydrobromide from cyanogen bromide and hydroxylamine in methyl alcohol. It is stable to acids, but is changed immediately by alkalis into an unstable red *azo body*, which becomes ultimately converted into *azoxybismethenylamidoxime*, $H_2NC(NOH).(N_2O)C(NOH)NH_2$, *hydrazodicarbonamide*, and other substances.

Amino-methyl-nitrosilic Acid,  $H_2NC\!<\!\genfrac{}{}{0pt}{}{NOH}{NO}$, is produced when alcoholic potassium hydroxide decomposes the above-mentioned intermediate azo-body. It consists of very unstable green tabular crystals, and combines to form blue or green salts; *potassium salt* is deposited from alcohol as steel blue brilliant needles (B. **38**, 1445).

NITRILES AND IMIDES OF CARBONIC AND THIOCARBONIC ACIDS

The nitriles, *cyanic acid, thiocyanic acid, cyanogen chloride,* and *cyanamide,* stand in a systematic and genetic connection with carbamic acid, thiocarbamic acid, urea chloride, and urea, as well as with thiourea:

NH_2COOH	NH_2COSH	NH_2COCl	NH_2CONH_2	NH_2CSNH_2
Carbamic Acid.	**Thiocarbamic Acid.**	**Urea Chloride.**	**Urea.**	**Thiourea.**

$N{\equiv}C.OH$	$N{\equiv}C.SH$	$N{\equiv}CCl$	$N{\equiv}C.NH_2$
Cyanic Acid.	**Thiocyanic Acid.**	**Cyanogen Chloride.**	**Cyanamide.**

The empirical formulæ of cyanic acid, HONC, thiocyanic acid, HSNC, and cyanamide, CN_2H_2, have each another structural formula:

$NH{=}C{=}O$	$NH{=}CS$	$NH{=}C{=}NH$
Isocyanic Acid, Carbimide.	**Isothiocyanic Acid, Thiocarbimide.**	**Carbodi-imide.**

Indeed, alkyl derivatives are known which correspond with both formulæ of each of these bodies. The isothiocyanic esters, or *mustard oils*, may be especially mentioned. The constitution of free cyanic acid, and of cyanamide, has not yet been determined with certainty, whilst the normal formula, $HS.C{\equiv}N$, is universally attributed to thiocyanic or sulphocyanic acid. Cyanic acid itself has received the iso-formula, $HN{=}C{=}O$, because it forms isocyanic esters with diazomethane (C. 1906, II. 1723).

The remarkable tendency of cyanic acid and cyanamide to polymerization is particularly noteworthy; the former substance gives rise to cyamelide and cyanuric acid, and the latter to dicyanodiamide and tricyanotriamide or melamine.

When the simple derivatives of cyanic acid have been discussed, then the corresponding trimolecular polymers will be described.

Numerous compounds containing the cyanogen group have been described and discussed in the preceding pages as nitriles of carboxylic acids (p. 278), hydroxy- and ketonic acids (pp. 378, 409, 466). The simplest body, *hydrogen cyanide* or *hydrocyanic acid* (p. 239), has been discussed with formic acid. Cyanic acid bears a relation to hydrocyanic acid similar to that of carbonic acid to formic acid.

OXYGEN DERIVATIVES OF CYANOGEN, THEIR ISOMERIDES AND POLYMERIDES

Cyanic Acid, HN:CO or HO:C.N, isomeric with fulminic acid or carbyloxime (p. 248), is obtained by heating polymeric cyanuric acid. The vapours which distil over are condensed in a strongly cooled receiver.

The acid is only stable below 0°, and is a mobile, very volatile liquid, which reacts strongly acid, and smells very much like glacial acetic acid. It produces blisters upon the skin. At about 0°, the aqueous solution is rapidly converted into carbon dioxide and ammonia:

$$HONC+H_2O=CO_2+HN_3.$$

At 0°, the liquid cyanic acid passes rapidly into the polymeric *cyamelide*—a white, porcelain-like mass, which is insoluble in water, and when distilled reverts to cyanic acid. Above 0°, the conversion of liquid cynanic acid into cyamelide and cyanuric acid (C. 1902, I. 526) occurs, accompanied by an explosive generation of froth (comp. formaldehyde, p. 197).

Cyamelide is also obtained by grinding together potassium cyanate and crystallized oxalic acid, and washing out with water. It is a loose white powder, only slightly soluble in all solvents. Prolonged boiling with water decomposes it into NH_3, CO_2, and partly into cyanuric acid (p. 463). When digested with concentrated sodium hydroxide solution it is converted completely into tri-sodium cyanurate. This probably corresponds with the formula $O<\begin{smallmatrix}C(NH).O\\C(NH).O\end{smallmatrix}>C(NH)$; it is therefore analogous to trioxymethylene (p. 199) (B. **38**, 1013). Cyanic acid dissolves in alcohols, yielding esters of allophanic acid (p. 444).

Potassium Cyanate, Potassium Isocyanate, *ordinary cyanate of potassium,* KO.C⋮N or KN:C:O, is formed in the oxidation of potassium cyanide in the air, or with some oxidant like lead oxide, minium, potassium permanganate (B. **36**, 1806), or sodium hypochlorite (B. **26**, R. 779). It is most conveniently made by heating small portions (3–5 gm.) of an intimate mixture of 100 parts potassium ferrocyanide and 75 parts of potassium bichromate in an iron dish, during which NH_3 should not be set free (B. **26**, 2438). It results, too, on conducting dicyanogen or cyanogen chloride into potassium hydroxide solution (B. **23**, 2201). The salt crystallizes in shining leaflets, resembling potassium chlorate, or in quadratic plates (B. **27**, 837), and dissolves readily in cold water, but with more difficulty in hot alcohol. In aqueous solution it decomposes rapidly into ammonia and potassium carbonate.

Potassium isocyanate precipitates aqueous solutions of the heavy metals. The lead, silver, and mercurous salts are white, the cupric salt is green in colour. Lead cyanate is quantitatively hydrolized to carbonate and urea when boiled with water (C. 1904, I. 160).

Ammonium cyanate, NH_4.OC⋮N or NH_4.N:C:O, is a white crystalline powder, formed by contact of cyanic acid vapours with dry ammonia, or by mixing ethereal solutions of cyanic acid and ammonia (C. 1900, I. 107). Potassium hydroxide decomposes it into potassium isocyanate and ammonia. On heating the dry salt to 60°, or by evaporating its aqueous solution it passes into the isomeric ***urea*** (p. 438). Similarly, cyanurates of primary and secondary amines are changed into alkylated ureas, whilst those of the tertiary amines remain unchanged.

The cyanates of the primary and secondary amines are similarly converted into alkyl ureas, whereas the salts of the tertiary amines remain unchanged.

Esters of Normal Cyanic Acid, *Cyanetholines,* RO—C≡N, are not known (A. **287**, 310). Imidocarbonic acid ethers (p. 445) are produced when cyanogen chloride acts on sodium alcoholates in alcoholic solution.

Esters of Isocyanic Acid, *Alkyl Carbimides* or *Alkyl Cyanates.*—*Würtz* prepared these, in 1848, (1) by distilling potassium ethyl sulphate with potassium isocyanate:

$$(C_2H_5)KSO_4+KN{:}CO=C_2H_5N{:}CO+K_2SO_4.$$

Esters of isocyanuric acid are formed at the same time, in consequence of polymerization. (2) Isocyanic esters are also produced by oxidizing the carbylamines with mercuric oxide:

$$C_2H_5.NC + O = C_2H_5.N{:}CO;$$

(3) by the action of silver isocyanate on alkyl iodides at low temperatures (together with esters of cyanuric acid, p. 463):

$$C_2H_5I + AgN{:}CO = C_2H_5N{:}CO + AgI;$$

and (4) by heating the dry mercuric chloride double salt of the alkyl carbamine thiolic acids (p. 449) (A. **359**, 202):

$$C_2H_5NH.CO.S.HgCl \longrightarrow C_2H_5N{:}CO + HgS + HCl.$$

These esters are volatile liquids, boiling without decomposition, and possessing a very disagreeable, penetrating odour, which provokes tears. They dissolve without decomposition in ether. On standing they pass rather rapidly into the polymeric isocyanuric esters.

Isocyanic Methyl Ester, $CH_3N{:}CO$, *Methyl Isocyanate, Methyl Carbimide*, b.p. 44°.
Isocyanic Ethyl Ester, $C_2H_5N{:}CO$, b.p. 60°.
Isocyanic Allyl Ester, $C_3H_5N.CO$, b.p. 82°.
Isocyanic Isobutyl Ester, $CONC_4H_9$, b.p. 101°.

Reactions.—In all their reactions they behave like carbimide derivatives, in which the alkyl group is united to nitrogen. (1) Heated with KOH they become primary amines and potassium carbonate (p. 159). This is the method *Würtz* used when he first discovered them.

(2) Acids in aqueous solution behave similarly:

$$C_2H_5N{:}CO + H_2O + HCl = CO_2 + C_2H_5NH_2.HCl.$$

(3) With the amines and ammonia they yield alkyl ureas (*q.v.*). (4) Water decomposes them at once into CO_2 and dialkyl ureas. In this decomposition amines form first, CO_2 being set free, and these combine with the excess of isocyanic ester to dialkyl ureas (*q.v.*).

(5) Fatty acids convert them into alkyl primary acid amides (p. 275), CO_2 being simultaneously evolved. (6) Acid anhydrides convert them into alkyl secondary acid amides (p. 276).

(7) The esters of isocyanic acid unite with alcohol, yielding esters of carbamic acid (p. 435).

(8) As derivatives of ammonia the isocyanic esters are capable of combining directly with the halogen acids. The products are *urea chlorides* (p. 437), from which the isocyanic esters are again separated by distillation with lime:

$$C_2H_5NCO \underset{Ca(OH)_2}{\overset{HCl}{\rightleftarrows}} C_2H_5.HNCO.Cl.$$

Glycocollic Ester Isocyanate, $OC{:}NCH_2CO_2C_2H_5$, $b.p._{15}$ 115-120°, is obtained from glycocollic ester hydrochloride by excess of phosgene in toluene. Water converts it into *carbiminodiacetic acid*, $CO(NHCH_2CO_2H)_2$, m.p. 167°. Other amino-acids yield corresponding mixed urea derivatives (C. 1906, II. 671).

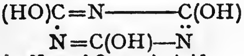
Acetyl Isocyanate, $OC{:}N.COCH_3$, b.p. 80°, is prepared by the action of acetyl chloride on mercury fulminate (p. 249), and on silver cyanate (B. **36**, 3214). Alcohol and ammonia convert it into acetyl urethane (p. 436) or monoacetyl urea (p. 441).

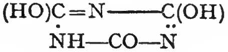
Methyl Sulphonyl Isocyanate, $CH_3SO_2N:CO$, m.p. 31°, b.p.$_{10}$ 73·5–75° (B. **38**, 2015).

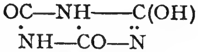
Carboxyethyl Isocyanate, $C_2H_5OCO.N:CO$, b.p. 116°, is produced from nitrogen tricarboxylic ester (p. 445) by means of P_2O_5. It unites with alcohol to form imido-carboxylic ester (p. 444); and with ammonia to form allophanic ester (p. 444). Water converts it to carboxyl diurethane (p. 445) (B. **39**, 686).

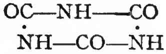
CYANURIC ACID AND ITS ALKYLIC DERIVATIVES

Just as with cyanic acid, so here with tricyanic acid, two structural cases are possible:

(1)

Normal Cyanuric Acid.

(2)


(3)

Intermediate Product.

(4)

Iso- or Pseudo-cyanuric Acid.

Ordinary solid cyanuric acid, like cyanic acid, is most probably to be represented by an imide, tricarbimide, or isocyanuric formula (4) When titrated with sodium hydroxide and phenolphtheleïn in aqueous solution, it behaves as a monobasic acid, yielding salts accordinto to formula (3). Two equivalents of alkali produce dibasic salts, corresponding with formula (2), which, on boiling, take up a third equivalent of the metal, and form stable, well-crystallizing tribasic salts, $C_3N_3O_3Me_3$ (formula 1), some of which are only slightly soluble in water. Corresponding with these consecutive desmotropic transformations (p. 38), the temperature coefficient of the electrical conductivity (taken as of a monobasic acid) of an aqueous solution of cyanuric acid increases with increasing temperature: the acid becomes stronger by a change of constitution as from formula 4 to 1 (B. **39**, 139). Its behaviour as a "pseudo-acid" is shown by the occurrence of isomeric mercury salts: *O-mercury cyanurate* $C_3N_3(OHg)_3$, obtained from trisodium cyanurate and mercury salts, is decomposed by alkalis; *N-mercury cyanurate*, $C_3O_3(NHg)_3$ is produced from free cyanuric acid and mercury salts, and is not decomposed by alkalis (B. **35**, 2717).

Esters can be obtained from all four formulæ, but only those in which the alkyl group is united to oxygen can be decomposed by alkalis (B. **38**, 1005). The cyanuric halides (p. 465) are derived from formula 1.

Cyanuric Acid, $C_3N_3O_3H_3$, was first observed by *Scheele* in the dry distillation of uric acid. It is produced (1) by heating tricyanogen chloride, $C_3N_3Cl_3$, or bromide (B. **16**, 2893) with water to 120–130°, or with alkalis. (2) Dilute acetic acid added to a solution of potassium isocyanate gradually separates primary potassium isocyanate, $C_3N_3O_3H_2K$, from which mineral acids liberate cyanuric acid. (3) It is formed, also, (*a*) on heating urea (*b*) or carbonyl diurea (p. 448); (*c*) on conducting chlorine over urea heated to 130–140°; (*d*) when urea is heated with a solution of phosgene in toluene to 190–230° (B. **29**, R. 866).

(*a*) $3CO(NH_2)_2 = C_3O_3N_3H_3 + 3NH_3$
(*b*) $NH_2CONH.CO.NHCONH_2 = C_3O_3N_3H_3 + NH_3$
(*c*) $3Cl + 3CO(NH_2)_2 = C_3O_3N_3H_3 + 2NH_4Cl + HCl + N$
(*d*) $3COCl_2 + 3CO(NH_2)_2 = 2C_3O_3N_3H_3 + 6HCl$.

The evidence in favour of a symmetrical structure for cyanuric acid depends on the successive substitution of the three chlorine atoms of cyanuric chloride by amido-, methylamido-, and ethylamido-groups, which always leads to the same acid-product, $C_3H_3(NH_2)$-$(NHCH_3)(NH.C_2H_5)$, whatever the order in which the three groups are introduced (B. **32,** 692).

Cyanuric acid crystallizes from aqueous solution with 2 molecules of water ($C_3N_3O_3H_3+2H_2O$) in large rhombic prisms. It is soluble in 40 parts of cold water, and easily soluble in hot water and alcohol. When boiled with acids it decomposes into carbonic acid and ammonia; when distilled it breaks up into cyanic acid. PCl_5 converts it into tricyanogen chloride.

Characteristic salts of the tribasic cyanuric acid are the trisodium salt and the amethyst-coloured cuprammonium salt (see above).

Normal Cyanuric Esters are formed (1) by the action of cyanogen chloride on sodium alcoholates.

(2) A simpler procedure is to act on the sodium alcoholates with cyanuric chloride or bromide (B. **18,** 3263 and **19,** 2063).

Methyl Cyanuric Ester, m.p. 135°, b.p. 263°.

Ethyl Cyanuric Ester, m.p. 29°, b.p. 275°.

The normal cyanuric esters on being digested with the alkalis, break up into cyanuric acid and alcohol. They combine with six atoms of bromine. PCl_5 converts them into cyanuric chloride. Boiling gradually changes them to isocyanuric esters.

Partial hydrolysis of the normal cyanuric esters by NaOH or $Ba(OH)_2$ gives rise to normal dialkyl cyanuric acids, which, when heated, rearrange themselves into dialkyl isocyanuric acids (B. **19,** 2067):

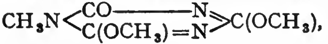
O-Dimethyl Cyanuric Acid, $C_3N_3(OCH_3)_2.OH$, m.p. 160–180°. *O-Dimethyl Cyanuric Acid Chloride,* $C_3N_3(OCH_3)_2Cl$, m.p. 81°, is prepared from cyanuric chloride, methyl alcohol and zinc dust (B. **36,** 3195).

Esters of Isocyanuric Acid, *Tricarbimide Esters,* $C_3O_3(NR)_3$, are formed together with the isocyanic esters, when the latter are prepared by the distillation of potassium cyanate with salts of alkyl sulphuric acid (p. 461). We have already spoken of their formation as a result of the molecular transposition of the cyanuric esters. Hence they are formed together with these, or appear in their stead in energetic reactions—*e.g.* in the distillation of potassium cyanate with ethyl sulphate, or when silver cyanurate is acted upon by alkyl iodides (B. **30,** 2616). They are solid crystalline bodies, soluble in water, alcohol, and ether, and may be distilled without decomposition. They pass into primary amines and potassium carbonate when boiled with alkalis, similarly to the isocyanates:

$$C_3O_3(NCH_3)_3+6KOH=3K_2CO_3+3NH_2CH_3.$$

Methyl Isocyanuric Ester, Trimethyl Carbimide, $C_3O_3(NCH_3)_3$, m.p. 176°, b.p. 296°.

Ethyl Isocyanuric Ester, $C_3O_3(NC_2H_5)_3$, m.p. 95°, b.p. 276°. It volatilizes with steam.

Mixed n.-Isocyanuric Acid Esters. *Methyl Cyanuric Dimethyl Ester,*  $CH_3N<\begin{array}{l}CO\text{———}N\\C(OCH_3)=N\end{array}>C(OCH_3)$, m.p. 105°, is prepared, together with other bodies, from silver cyanate and iodomethane by prolonged contact in the cold. It can be sublimed undecomposed in the cold, and is hydrolyzed by hydrochloric acid into *ψ-methyl cyanuric acid,* $CH_3N(C_3O_3N_2H_2)$, m.p. 296°. This also results from the action of boiling alkalis on carbonyl dimethyl urea (p. 445).

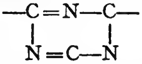
Dimethyl Cyanuric Methyl Ester,  $CH_3N<\begin{array}{l}CO—N(CH_3)\\CO—N=\!=\!=\end{array}>C(OCH_3)$, m.p. 118°, is produced from silver cyanurate and iodomethane in the cold. Hydrolysis gives rise to *Dimethyl ψ-Cyanuric Acid,* $(CH_3N)_2(C_2O_3NH)$, m.p. 222°, which is also obtained by heating *n.*-dimethyl cyanuric acid (see above) (B. **88,** 1005).

Cyanuric Triacetate, $C_3N_3O_3(COCH_3)_3$, m.p. 175° with decomposition, is produced from silver cyanurate and acetyl chloride.

Cyanuric Tricarbonic Ester, $(C_3N_3O_3)(CO_2C_2H_5)$, results from the polymerization of cyanocarbonic acid ester (p. 484). It is very slightly soluble, except in chloroform (B. **38,** 1010).

Cyanuric Triurea, $(C_3N_3O_3)(CONH_2)_3$, is formed, together with cyanuric acid, when urea is heated to 200°, or with cyanuric bromide. It is amorphous and slightly soluble. It forms a ***trisodium*** salt, which crystallizes with $5H_2O$ (B. **38,** 1010).

HALOGEN COMPOUNDS OF CYANOGEN AND ITS POLYMERS

The halogen compounds of cyanogen result from the action of halogens on metallic cyanides, such as mercury cyanide, and on aqueous hydrocyanic acid. The chloride and bromide condense to tricyanides in which the C_3N_3 group  $\begin{matrix}-C=N-C- \\ | \quad\quad | \\ N=C-N\end{matrix}$ constitutes the radical of normal cyanuric acid. On account of their connection on the one hand with cyanic and cyanuric acids and on the other with hydrocyanic acid and its salts, the cyanogen halides can be looked on as being either halogen compounds of the anhydride of ***n.***-cyanic acid or the halogen imides of carbon monoxide, *e.g.*:

HN=C	ClN=C or ClC≡N	HOC≡N
Hydrocyanic Acid. Carbonyl Imide.	Cyanogen Chloride.	*n*-Cyanic Acid.

The formula XN:C receives substantiation from the fact that cyanogen halides easily yield hydrocyanic acid; also that the cyanogen chloride and alcoholic sodium ethoxide do not yield the normal cyanic ether (p. 461), but imidocarbonic ether, a reaction which is best explained as taking place with the intermediate formation of NaNC and hypochlorous acid ester (p. 446) (C. 1092, I. 525, 862). Contrary to this is the reaction of cyanogen chloride with mercaptides to form alkyl thiocyanates (p. 468), and with ammonia to produce cyanamide (p. 471).

Cyanogen Chloride, CNCl, m.p. —5°, b.p. 15°, is produced by the action of chlorine on aqueous hydrocyanic acid or on a cold mercuric cyanide solution, or better, on a solution of potassium cyanide and zinc sulphate (C. 1907, I. 746). It is a mobile liquid. After some time it passes spontaneously into cyanuric chloride. With ammonia, it yields ammonium chloride and cyanamide, $NH_2.NC$. Alkalis decompose it into metallic cyanides and isocyanates.

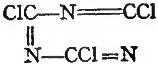
Cyanogen Bromide, CNBr, m.p. 52°, b.p. 61°, is produced on adding a potassium cyanide solution drop by drop to bromine, when well cooled (B. **29,** 1822). For the reaction of cyanogen bromide and tertiary amines, see p. 472, etc.

Cyanogen Iodide, CNI, sublimes at 45°, without melting, in brilliant white needles.

These compounds are sparingly soluble in water, but they dissolve readily in alcohol and ether. Their vapours have a penetrating odour, provoking tears, and act as powerful poisons.

Cyanuric halides are converted into cyanuric acid when heated with water.

Tricyanogen Chloride, *Cyanuric Chloride, Solid Chlorocyanogen*



$$\begin{array}{l}\mathrm{ClC{-}N{=}CCl}\\ \;\Vert\\ \;\mathrm{N{-}CCl{=}N}\end{array}$$

m.p. 146°, b.p. 190°, is produced (1) when liquid cyanogen chloride is kept in sealed tubes, during which polymerization 189·05 Cal. are liberated (C. 1897, I. 284). It is formed (2) directly by leading chlorine into an ethereal solution of HNC, or into anhydrous hydrocyanic acid exposed to direct sunlight (B. **19**, 2056), or better, by slowly dropping HNC into a saturated solution of chlorine in chloroform (B. **32**, 691); (3) also by the distillation of cyanuric acid, $H_3O_3N_3C_3$, with PCl_5 (A. **116**, 357). When boiled with water or alkalis, it breaks up into hydrochloric and cyanuric acids (B. **19**, R. 599). The chlorine atoms of cyanogen chloride can be successively substituted by amido- and alkylamido-groups, whereby cyanuramine chlorides, cyanuralkylamine chlorides (p. 474), melamines, and alkyl melamines (p. 473) are formed (B. **32**, 693).

Trichloryl Isocyanuric Acid, $\begin{array}{l}\mathrm{OC.NCl.CO}\\ /\qquad\quad\;\vert\\ \mathrm{NCl.CO.NCl}\end{array}$, m.p. 245°, is formed by the action of chlorine on potassium cyanurate. It is a nitrogen chloride, since it evolves chlorine with hydrochloric acid, and regenerates cyanuric acid with NH_3 or H_2S (C. 1902, I. 525, 804).

Cyanuric Bromide, $C_3N_3Br_3$, m.p. above 300°, is produced (1) from bromocyanogen in the presence of a little bromine. (2) On heating the anhydrous bromide or its ethereal solution in sealed tubes to 130–140°. (3) By heating dry potassium ferrocyanide and also ferricyanide with bromine at 250° (B. **16**, 2893), or (4) on conducting HBr into the ethereal solution of CNBr (B. **18**, 3262). It is volatile at temperatures above 300°.

Cyanuric Iodide, $C_3N_3I_3$, is produced by the action of hydriodic acid on cyanuric chloride. It is a dark brown, insoluble powder. At 200° it readily breaks up into iodine and paracyanogen, $(CN)_n$ (B. **19**, 599).

SULPHUR COMPOUNDS OF CYANOGEN, THEIR ISOMERS AND POLYMERS

The two possible structurally isomeric thiocyanic acids correspond with the two possible isomeric cyanic acids.

$$\underset{\text{Thiocyanic Acid, Sulphocyanic Acid.}}{\mathrm{HS{-}C{\equiv}N}} \quad \text{and} \quad \underset{\text{Isothiocyanic Acid, Sulphocarbimide.}}{\mathrm{NH{=}C{=}S.}}$$

The known thiocyanic acid and its salts (having the group **NC.S—**) are constituted according to the first formula. Its salts are obtained from the cyanides by the addition of sulphur (p. 242), just as the isocyanates result by the absorption of oxygen. The different union of sulphur and oxygen in this instance is noteworthy:

$$\mathrm{KNC+O=KN{:}CO} \qquad \mathrm{KNC+S=KS.CN.}$$

Isothiocarbimide, Sulphocarbimide, HN.CS, and its salts are not known. Its esters (the mustard oils) do, however, exist and are isomeric with those of thiocyanic acid.

Thiocyanic Acid, Sulphocyanic Acid, HS.CN, m.p. 5° (approx.), occurs in small quantities in the human stomach (B. **28**, 1318), and is obtained by distilling its potassium salt with dilute sulphuric acid. At 0° it forms a white crystalline mass and exercises a strongly irritating action on the mucous membrane. On melting it forms a yellow liquid which at ordinary temperatures solidifies to yellow needles accompanied by a considerable evolution of heat. It is very easily soluble in water, alcohol, and ether. The aqueous solution also precipitates polymerization products at ordinary temperatures after a short time (B. **40**, 3166). Free thiocyanic acid and its soluble salts colour a weakly acid solution of ferric salts a dark-red colour (C. 1901, II. 199), constituting a highly sensitive reaction, which depends on the formation of $Fe_2(CNS)_6+9KSNC$, when the potassium salt is employed (B. **22**, 2061). This reaction gives rise to the alternative name rhodonates (ῥόδον, rose), which is sometimes given to these compounds. Strong acids decompose thiocyanic acid into hydrocyanic acid and *perthiocyanic acid*, $C_2N_2S_3H_2$ (p. 468).

The *alkali thiocyanates*, like the isocyanates, are obtained by fusing the cyanides with sulphur.

Potassium Thiocyanate, KS.CN, crystallizes from alcohol in long, colourless prisms, which deliquesce in the air. The *sodium salt* is very deliquescent, and occurs in the saliva and urine of different animals. When heated with zinc dust it is converted into potassium cyanide (C. 1897, I. 270).

Potassium Selenocyanate, KSeNC, corresponds with the thiocyanate, and is formed when potassium cyanide and selenium are melted together. It can be crystallized from alcohol. NO_2 causes the formation of *Cyanogen Triselenide*, $C_2N_2Se_3$, m.p. 132°, obtained as yellow leaflets from benzene solution. These substances can be used for the preparation of pure selenium (B. **33**, 1765).

Ammonium Thiocyanate, $NH_4S.CN$, m.p. 150°, is formed on heating hydrocyanic acid with yellow ammonium sulphide, or a solution of ammonium cyanide with sulphur. It is most readily obtained by heating CS_2 with alcoholic ammonia (comp. Ammonium Dithiocarbamate, p. 449):

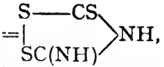
$$CS_2+2NH_3 \longrightarrow H_2N.CSSNH_4+2NH_3 \longrightarrow NH_4S.C{:}N+(NH_4)_2S.$$

The salt crystallizes in prisms, which readily dissolve in water and alcohol. At 170–180° molecular transposition into thiourea occurs (similarly to ammonium cyanate, p. 438).

The salts of the heavy metals are mostly insoluble. The *mercury salt*, $Hg(CN.S)_2$, is a gray, amorphous precipitate, which burns on ignition and swells up strongly (Pharaoh's serpents); *silver salt*, AgSNC, is a precipitate similar to silver chloride. The volumetric method of *Volhard* is based on its production (A. **190**, 1); *lead sulphocyanide*, $Pb.(CNS)_2$.

Cyanogen Sulphide, *Thiocyanic Anhydride*, $(CN)_2S$, m.p. 65°, is formed when cyanogen iodide in ethereal solution acts on silver thiocyanate. It sublimes at 30°, and dissolves in water, alcohol, and ether.

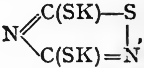
Xanthane Hydride, *Imidothiodisulphazolidine*, $C_2H_2H_2S_3=$

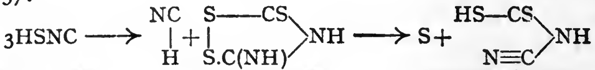


$$\begin{array}{l}S\text{—}CS\\ |\\ SC(NH)\end{array}\!\!\Big\rangle NH,$$

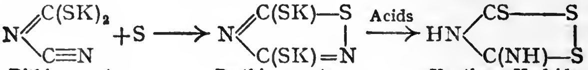
s prepared by decomposing a concentrated solution of thiocyanic acid, whereby hydrocyanic acid is driven off. It forms prisms soluble with difficulty in water and most other solvents.

Dithiocyanic Acid, $C_2N_2H_2S_2$=HSCS,NH.CN, is produced when alkalis act n the cold on xanthane hydride, when sulphur is thrown out and the dipotassium alt of the acid is formed. It is also prepared from cyanamide, carbon disulphide, and alcoholic potassium hydroxide. These modes of formation show the acid o be *cyanamidodithiocarbonic acid*, $(HS)_2C$=NCN or HS_2CNHCN. The free acid consists of yellow needles, and is unstable, the potassium salt even decomposing in aqueous solution into two molecules of potassium thiocyanate; *Dimethyl Ester*, $(CH_3S)_2C$: NCN, m.p. 57°, is decomposed by hydrochloric acid at 200° into mercaptan, NH_3, and CO_2.

Perthiocyanic Acid, $C_2N_2S_3H_2$; salts,  are formed when an alkaline solution of dithiocyanic acid is boiled with sulphur. The acid is structurally isomeric with xanthane hydride, which possesses a neutral reaction, into which it very rapidly changes in acid solution; *Dimethyl Ester*, $C_2N_2S(SCH_3)_2$, m.p. 42°, b.p. 279°, is decomposed by hydrochloric acid into CH_3SH, NH_4Cl, and CO_2. The following shows the connection between these peculiar reactions (**A. 331**, 265):



Thiocyanic Acid. Xanthane Hydride. Dithiocyanic Acid.



Dithiocyanate. Perthiocyanate. Xanthane Hydride.

Cyanogen Sulphide, $(CNS)_x$ and *Pseudocyanogen Sulphide*, are the yellow amorphous products which result when the alkali and alkali earth thiocyanates are oxidized. Cyanogen sulphide is also formed when dry thiocyanates are treated with dry halogens, whilst pseudocyanogen sulphide, which appears to be a mixture of various substances in varying proportions, is obtained from an aqueous solution of thiocyanates with halogens, nitric acid, H_2O_2, or persulphates. Cyanogen sulphide, and to a much smaller extent pseudocyanogen sulphide, when treated with water or sodium hydroxide solution yields *canarine*, $C_8N_8S_7H_4O$, a yellow substantive dye for cotton (one which does not require a mordant). It possesses a weakly acid reaction. Together with canarine there is formed a yellow, non-dying substance. $C_3N_4H_4S_2O$, which is decomposed by alkali sulphydrates into *thioammeline*, $(CN)_3(NH_2)_2SH$, and *dithiomelanurenic acid*, *aminodithiocyanuric acid*, $(CN)_3(NH_2)(SH)_2$ (J. pr. Ch. [2] **64**, 439).

Alkyl Thiocyanates, esters of *normal sulphocyanic acid* are obtained (1) by distilling potassium thiocyanate with salts of sulphuric acid ethers or with alkyl iodides:

$$KSCN+C_2H_5I=C_2H_5SCN+KI.$$

Further, (2) by the action of CNCl on salts of the mercaptans:

$$C_2H_5SK+CNCl=C_2H_5SCN+KCl.$$

They are liquids, insoluble in water, and possessing a leek-like odour. Nascent hydrogen (zinc and sulphuric acid) converts them into hydrocyanic acid and mercaptans:

$$C_2H_5S.CN+H_2=HNC+C_2H_5.SH.$$

On digesting with alcoholic potassium hydroxide, potassium thiocyanate is formed, whilst the isomeric mustard oils do not yield any potassium thiocyanate. Boiling nitric acid oxidizes them to alkyl sulphonic acids (p. 146) with separation of the cyanogen group. This would prove that the alkyl group in these bodies is linked directly to sulphur.

Methyl Thiocyanic Ester, CH_3SCN, m.p. 133°, $D_0=1{\cdot}080$. When heated to 180–185° it is converted into the isomeric methyl isothiocyanic ester. This conversion is more readily effected with allyl thiocyanate (see **Allyl Mustard Oil**, p. 470; C. 1901, II. 1115).

Ethyl Thiocyanic Ester, $C_2H_5S.CN$, b.p. 142°.

Isopropyl Thiocyanic Ester, C_3H_7SCN, b.p. 152°.

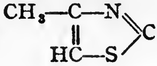
Allyl Thiociocyanic Ester, $C_3H_5S.CN$, b.p. 161°, and rapidly changes to isomeric allyl mustard oil.

Thiocyanic Compounds derived from Aldehydes, Glycols, Hydroxy-Ketones and Hydroxy-Fatty Acids.

Methylene Thiocyanate, Dithiocyanomethane, $CH_2(SCN)_2$, m.p. 107° (**B. 7**, 1282), is oxidized to methylene disulphonic acid (p. 210) (C. 1898, I. 886).

Ethylene Thiocyanate, Dithiocyanoethane, $NCS.CH_2CH_2.SCN$, m.p. 90° (**B. 23**, 1083). *Ethylene Selenocyanide*, m.p. 138° (**B. 23**, 1092).

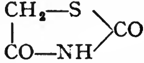
Thiocyanacetone, $CNSCH_2.CO.CH_3$, $D_{20}=1{\cdot}180$, is formed from barium thiocyanide and chloracetone (p. 224). It is an oil with scarcely any colour. It is somewhat soluble in water, and very readily soluble in ether. The alkali carbonates cause a rearrangement into *methyl oxythiazole,*



(B. **25,** 3648).

Thiocyanacetic Acid, Sulphocyanacetic Acid, $CNS.CH_2CO_2H$, is formed by the action of chloracetic acid on KCNS. It is a thick oil; *ethyl ester,* b.p. about 220°, prepared from chloracetic ester.

On boiling the latter with concentrated hydrochloric acid, it takes up water, loses alcohol, and *thiocyanacetic acid,*



is formed (A. **249,** 27). Many of the reactions of this cyanacetic acid are better explained by the constitutional formula, $SCNCH_2COOH$ (or perhaps $HC{<}{}^{S}_{N}{>}CHCOOH$) (comp. J. pr. Ch. [2] **66,** 172).

These heterocyclic bodies, derived from the products of the interaction of ammonium thiocyanate with *a*-chloroketones and *a*-chloro-fatty acids, belong to the class of *thiazoles* (Vol. II.).

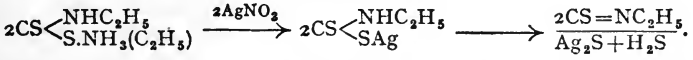
Mustard Oils, *Esters of Isothiocyanic Acid, Alkyl Thiocarbimides.*

The esters of isothiocyanic acid, HN : CS, not known in a free condition, are termed mustard oils, from their most important representative. They may also be considered as sulphocarbimide derivatives.

They are *produced* (1) by the rearrangement of the isomeric *alkyl thiocyanates* on the application of heat (p. 468):

$$C_3H_5SNC \longrightarrow C_3H_5NCS.$$

(2) From *primary amines.* These combine (*a*) with CS_2 in ethereal solution to form alkyl ammonium alkyl dithiocarbamates (B. **23,** 282). (*b*) On adding silver nitrate, mercuric chloride (B. **29,** R. 651) or ferric chloride (B. **8,** 108) to the aqueous solution of these salts, formed with primary amines, and then (*c*) heating to boiling the metallic compounds first precipitated, whereby they are decomposed into metallic sulphides, hydrogen sulphide and mustard oils.



$$2CS{<}{}^{NHC_2H_5}_{S.NH_3(C_2H_5)} \xrightarrow{2AgNO_3} 2CS{<}{}^{NHC_2H_5}_{SAg} \longrightarrow \frac{2CS{=}NC_2H_5}{Ag_2S+H_2S}.$$

The *mustard oil test* for the detection of primary amines (p. 163) was worked out by *A. W. Hofmann.*

* Iodine, too, forms mustard oils from the alkyl-ammonium salts of the alkyl dithiocarbamic acids (comp. isothiouranic disulphides).

(3) By the action of dialkyl thioureas (p. 452) with phosphorus pentoxide (B. **14,** 985); and (4) from isocyanic esters and P_2S_5 (B. **18,** R. 72).

Properties.—The mustard oils are liquids, almost insoluble in water, and possess a very penetrating odour, which provokes tears. They boil at lower temperatures than the isomeric thiocyanic esters.

Reactions.—(1) When heated with hydrochloric acid to 100°, or with H_2O to 200°, they break up into primary *amines*, hydrogen sulphide, and carbon dioxide (C. 1899, I. 885):

$$C_2H_5NCS+2H_2O=C_2H_5NH_2+CO_2+H_2S.$$

(2) When heated with a little dilute sulphuric acid, *carbon oxysulphide*, COS, is formed, together with the amine. (3) When heated with carboxylic acids they yield alkylated acid amides and COS; and (4) with carbonic anhydrides, diacidyl amides and COS (B. **26**, 2648). (5) Nascent hydrogen (zinc and hydrochloric acid) converts them into thioformaldehyde (p. 209) and primary amines:

$$C_2H_5NCS+2H_2=CSH_2+C_2H_5NH_2.$$

(6) When the mustard oils are heated with absolute alcohol to 100°, or with alcoholic potassium hydroxide, they pass into sulphourethanes. (7) They unite with ammonia and amines, yielding alkyl thioureas (*q.v.*). (8) Upon boiling their alcoholic solution with HgO or $HgCl_2$, a substitution of oxygen for sulphur occurs, with formation of esters of isocyanic acid, which immediately yield the dialkyl ureas when treated with water (see p. 440). (9) Consult A. **285**, 154, for the action of the halogens on the mustard oils.

Methyl Mustard Oil, CH_3NCS, *Methyl Isothiocyanic Ester, Methyl Sulphocarbimide*, m.p. 34°, b.p. 119°.

Ethyl Mustard Oil, b.p. 133°, $D_0=1·019$. *Propyl Mustard Oil*, b.p. 153°. *Isopropyl Mustard Oil*, b.p. 137°.

n.-*Butyl Mustard Oil*, b.p. 167°. *Isobutyl Mustard Oil*, b.p. 162°.

Tert.-Butyl Mustard Oil, b.p. 142°. n.-*Hexyl Mustard Oil*, b.p. 212°. *Heptyl Mustard Oil*, b.p. 238° (B. **29**, R. 651). Sec.-*Octyl Mustard Oil*, b.p. 232°.

On account of its occurrence the following is noteworthy: sec.-*Butyl Mustard Oil*,  $CS{:}NCH{<}\genfrac{}{}{0pt}{}{C_2H_5}{CH_3}$, b.p. 159·5°, $D_{12}=0·944$, is found in the ethereal oils of spoon wort (or scurvy grass) (*Cochlearia officinalis*); it is dextro-rotatory to polarized light, and on decomposition gives a dextro-rotatory sec.-butylamine (C. 1901, II. 29).

The most important of the mustard oils is the common or—

Allyl Mustard Oil, *Allyl Isothiocyanic Ester*, $C_3H_5N:CS$, b.p. 150·7°, $D_{10}=1·017$, the principal constituent of ordinary mustard oil, is obtained by distilling powdered black mustard seeds (*Sinapis nigra*), or radish oil from *Cochlearia armoracia*, with water. Mustard seeds contain potassium *myronate* (see *Glucosides*, Vol. II.), which in the presence of water, under the influence of a ferment, *myrosin* (also present in the seed), breaks up into dextrose, potassium hydrogen sulphate, and *mustard oil*.

The reaction occurs even at 0°, and there is a small amount of allyl thiocyanate produced at the same time:

$$C_{10}H_{18}KNO_{10}S_2=C_6H_{12}O_6+KHSO_4+C_3H_5NCS.$$

Mustard oil is artificially prepared by distilling allyl iodide or bromide with alcoholic potassium or silver thiocyanate (*Gerlich*, A. **178**, 80; C. 1906, II. 1063):

$$KSCN+C_3H_5I=C_3N_5NCS+KI;$$

a molecular rearrangement occurs here.

Pure allyl mustard oil is a liquid not readily dissolved by water.

It has a pungent odour and causes blisters upon the skin. When heated with water or hydrochloric acid the following reaction ensues:

$$C_3H_5NCS+2H_2O=CO_2+H_2S+C_3H_5NH_2.$$

It unites with aqueous ammonia to form allyl thiourea (p. 452). When heated with water and lead oxide it yields diallyl urea (p. 440).

Acyl Thiocarbimides, or *Acyl Thiocyanates*, are produced by the action of fatty-acid chlorides, dissolved in benzene, on lead thiocyanate. *Acetyl Thiocyanate Thiocarbamide*, $CH_3CO(NCS)$, *Valeryl Thiocarbimide*, $C_4H_9CO.NCS$ (B. **29**, R. 85), and *Carboxethyl Thiocarbimide*, $C_2H_5OCO.NCS$, b.p.$_{21}$ 66° (B. **29**, R. 514), were obtained in this manner. Amines combine with them to form either alkylamides, AcNHR and aminothiocyanates, or acyl alkyl thioureas, AcNHCSNHR (C. 1905, I. 1098; 1906, II. 773, etc.).

Thio- or sulphocyanuric Acid, $(HS)_3C_3N_3$, corresponds with cyanuric acid. Isothiocyanuric acid is as little known as isocyanuric acid. Thiocyanuric acid results from cyanuric chloride (p. 466) and potassium hydrosulphide. It consists of small yellow needles, which decompose but do not melt above 200°.

Its *esters* result when cyanuric chloride and sodium mercaptides interact, and by the polymerization of the thiocyanic esters, RS.CN, when heated to 180° with a little HCl. More HCl causes them to split up into cyanuric acid and mercaptans.

Methyl Ester, $(CH_3S)_3C_3N_3$, m.p. 188°, yields *melamine* with ammonia (p. 473) (B. **18**, 2755). *Monothiocyanuric Dimethyl Ester*, $(SH)(OCH_3)_2C_3N_3$, is prepared from *O*-dimethyl cyanuric chloride (p. 464) and KSH. When hydrolyzed with HCl, it yields *monothiocyanuric acid*, $(HS)(HO)_2C_3N_3$, which gives a characteristic mercury salt (B. **36**, 3196).

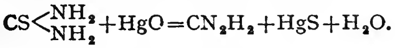
Isothiocyanuric Esters, $(RN)_3C_3S_3$, appear to have been formed by the polymerization of mustard oils with potassium acetate (B. **25**, 876).

CYANAMIDE AND THE AMIDES OF CYANURIC ACID

Cyanamide, $CN.NH_2$, m.p. 40°, the nitrile of carbamic acid, absorbs water and passes into urea, the amide of carbamic acid. It shows certain reactions, which would rather point to its being NH=C=NH, *carbodiimide*. It is formed (1) by the action of chloro- or bromo-cyanogen on an ethereal or aqueous solution of ammonia (*Bineau*, 1838; *Cloëz* and *Cannizzaro*, 1851):

$$CNCl+2NH_3=CN.NH_2+NH_4Cl;$$

and also (2) by the desulphurizing of thiourea by means of mercuric chloride, lead peroxide, or mercuric oxide (B. **18**, 461; A. **331**, 282); or lead hydroxide in presence of alkalis (C. 1897, I. 367):



$$CS{<}\begin{matrix}NH_2\\NH_2\end{matrix}+HgO=CN_2H_2+HgS+H_2O.$$

(3) By mixing urea with thionyl chloride:

$$CO(NH_2)_2+SOCl_2=CN_2H_2+SO_2+2HCl.$$

(4) Salts of cyanamide with sodium, calcium, etc., are prepared on a technical scale, and yield cyanamide when decomposed with acids:

(*a*) Sodium amide and carbon or carbon compounds heated to 400–600° produce sodium cyanamide (C. 1905, II. 1650, etc.):

$$2NH_2Na+C \longrightarrow CN_2Na_2+4H.$$

At 800° another atom of carbon enters into reaction and sodium cyanide, NaNC, is produced (C. 1904, I. 64).

(*b*) Calcium carbide, mixed with certain substances such as calcium chloride, and when heated to high temperatures, absorbs nitrogen and is converted into calcium cyanamide (C. 1905, II. 1059; B. **40**, 310, etc.):

$$C_2Ca + N_2 \longrightarrow CN_2Ca + C.$$

(*c*) Carbonates, such as these of barium and lead, react with ammonia at temperatures of incandescence, yielding metallic cyanamides (C. 1913, I. 677):

$$PbCO_3 + 2NH_3 \longrightarrow CN_2Pb + 3H_2O.$$

Cyanamide forms colourless crystals, easily soluble in water, alcohol, and ether. If heated it polymerizes to *dicyandiamide* and *tricyantriamide* (*melamine*).

Salts.—It forms salts with strong acids, but these are decomposed by water. It also forms salts with metals. An ammoniacal silver nitrate solution throws down a yellow precipitate, $CN.NAg_2$,from its solutions.

Reactions.—(1) By the action of sulphuric acid or hydrochloric acid, it absorbs water and becomes urea (p. 439). (2) H_2S converts it into thiourea (p. 451), and (3) NH_3 into guanidine (p. 455), whilst substituted guanidines are produced upon introducing the hydrochlorides of primary amines. (4) Alcohols and hydrochloric acid change cyanamide into isourea-ether (p. 446).

Mono-Alkyl Cyanamides are obtained (1) by the action of cyanogen chloride on primary amines in etheral solution, or from aqueous solutions of amines and potassium cyanide with bromine (C. 1906, II. 1046); (2) by heating alkyl thioureas with mercuric oxide and water.

Methyl Cyanamide, $CN.NHCH_3$, and *Ethyl Cyanamide*, $CN.NHC_2H_5$, are non-crystallizable, thick syrups with neutral reaction. They are readily converted into polymeric isomelamine derivatives.

Allyl Cyanamide, $CN.NHC_3H_5$, called *Sinamine*, is obtained from allyl thiourea. It is crystalline and polymerizes readily into triallyl melamine.

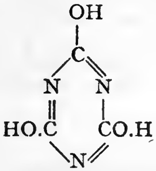
Dialkyl Cyanamides are formed from CNBr, or KNC+Br (C. 1906, II. 1046) and sec.- bases; also from silver cyanamide, $CN.NAg_2$, and iodo-alkyls. Further, from CNBr and tert.-amines, whereby the first formed *trialkyl cyanammonium bromide*, $R.R'R''N{<}^{CN}_{Br}$, probably parts with *bromo-alkyl*—the smallest of the alkyl radicals being lost. Alkyl and benzyl radicals, however, behave exceptionally, and are split off even more easily than the methyl group (B. **35**, 1279). On the use of these methods for breaking down tertiary cyclic amines, see B. **40**, 3914. *Dimethyl Cyanamide, Cyanodimethylamine*, $CN_2N(CH_3)_2$, b.p.$_{10}$ 68°; *Ethyl Cyanamide*, $CN.N(C_2H_5)_2$, b.p. 188°, is decomposed, when boiled with hydrochloric acid, into CO_2, NH_3 and diethylamine $NH(C_2H_5)_2$. *Cyanodipropylamine*, b.p.$_{15}$ 89°. *Cyanodiamylamine*, b.p.$_{10}$ 130°. Treated with ammonia and sulphuretted hydrogen in alcoholic solution, the cyano-dialkylamines are easily converted into the corresponding thioureas (B. **32**, 1872).

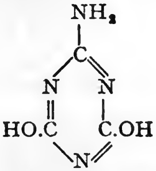
An example of a dialkyl-substituted carbodiimide is *Di*-n.-*propyl Carbodiimide*, $C(=N.C_3H_7)_2$, b.p. 177°, which is produced from sym.-dipropyl thiourea and H_2O (B. **26**, R. 189).

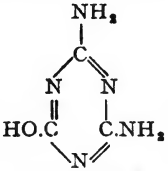
For the conversion of cyanamide into cyanamidocarbonic acid, cyanamidodicarbonic acid, cyanamidodithiocarbonic acid, see pp. 445, 467.

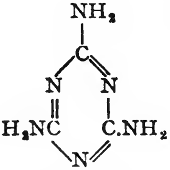
AMIDES OF CYANURIC ACID AND IMIDES OF ISOCYANURIC ACID

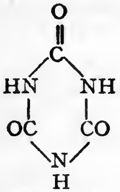
Three amides are derived from cyanuric acid, and three imides from hypothetical isocyanuric acid, the pseudo- form of cyanic acid (p. 463):

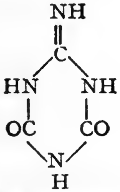

Normal Cyanuric Acid.

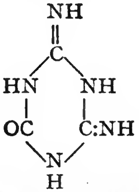

Cyanuromonamide, Ammelide.

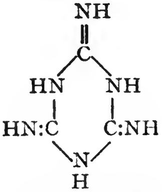

Cyanurodiamide, Ammeline.


Cyanurotriamidt Melamine.


Isocyanuric Acid.


Isocyanuromonimide.


Isocyanurodiimide, Isoammeline.


Isocyanurotriimide Isomelamine.

Melamine, *Cyanuramide,* $C_3N_3(NH_2)_3$, is obtained as thiocyanate by: (1) The rapid heating of ammonium thiocyanate (B. **19**, R. 340) (together with *melam* and *melem*); (2) the polymerization of cyanamide or dicyandiamide on heating to 150° (together with melam); (3) by heating methyl trithiocyanuric ester to 180° with concentrated ammonia; and (4) by heating cyanuric chloride to 100° with concentrated ammonia (B. **18**, 2765):

$$C_3N_3Cl_3+6NH_3=C_3N_3(NH_2)_3+3NH_4Cl.$$

Melamine is nearly insoluble in alcohol and ether. It crystallizes from hot water in shining monoclinic prisms. It sublimes on heating and decomposes into *mellon* and NH_3. It forms crystalline salts with 1 equivalent of acid. Molten potassium hydroxide converts it into potassium cyanate.

On boiling with alkalis or acids melamine splits off ammonia and passes successively into *Ammeline*, $C_3H_5N_5O=C_3N_3(NH_2)_2.OH$, a white powder insoluble in water, but soluble in alkalis and mineral acids (B. **21**, R. 789); *Ammelide, Melanurenic Acid*, $C_3H_4N_4O_2=C_3N_3(NH_2)(OH)_2$, a white powder which forms salts with both acids and bases, and finally cyanuric acid, $C_3N_3(OH)_3$ (B. **19**, R. 341).

Melanurenic Acid is formed from melam and melem (see below), when heated with concentrated H_2SO_4 (B. **19**, R. 341; **18**, 3106).

Melam, $C_6H_9N_{11}=[(NH_2)_2C_3N_3]_2NH$ (?),
Melem, $C_6H_6N_{10}=[(NH_2)C_3N_3(NH)]_2$ (?),
and *Mellon*, $C_6H_3N_9=C_3N_3(NH)_3C_3N_3$ (?),

are formed **by heating** ammonium thiocyanate, the first two **at** 200°, and the last at red heat. They are amorphous white substances (B. **19**, R. 340).

Alkyl Derivatives of the Melamines.

Whilst melamine is only known in one form as cyanurotriamide, two series of isomeric alkyl derivatives exist—obtained from normal melamine and hypothetical isomelamine:

(1) $C_3N_3(NHR')_3$ and $C_3N_3(NR'_2)_3$.
Normal Alkyl Melamines.

(2) $C_3N_3H_3(NR')_3$.
Isoalkyl Melamines.

These are distinguished from each other not only by the manner of their preparation, but also by their reactions.

(1) **Normal Alkyl Melamines** are obtained from the trithiocyanuric esters, $C_3N_3(S.CH_3)_3$, and from cyanuric chloride, $C_3N_3Cl_3$, upon heating with primary and secondary amines (B. **18**, R. 498):

$$C_3N_3Cl_3+3NH(CH_3)_2=C_3N_3[N(CH_3)_2]_3.$$

Heating with concentrated hydrochloric acid causes them to split up into cyanuric acid and the constituent alkylamines.

Trimethyl Melamine, $C_3N_3(NH.CH_3)_3$, m.p. 130°, dissolves readily in water, alcohol and ether. *Triethyl Melamine*, $C_3N_3(NH.C_2H_5)_3$, crystallizes in needles, m.p. 74° C.

Methyl Ethyl Melamine, $C_3H_3(NHC_2H_5)(NHCH_3)NH_2$, m.p. 176°, is prepared from cyanuric chloride by the successive substitution of NH_2-, CH_3NH-, and C_2H_5NH- groups, it being immaterial in which order the groups are introduced. On the significance of these compounds to the constitution of cyanuric chloride, see p. 463.

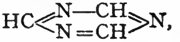
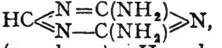
Hexamethyl Melamine, $C_3N_3[N(CH_3)_2]_3$, m.p. 171°, *Hexaethyl Melamine*, $C_3N_3[N(C_2H_5)_2]_3$, is a liquid, which is decomposed by hydrochloric acid into cyanuric acid and 3 molecules of diethylamine.

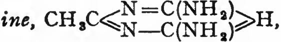
(2) **Alkyl Isomelamines** are formed by the polymerization of the alkyl cyanamides, CN.NHR′ (p. 472), upon evaporating their solutions, obtained from the alkyl thioureas on warming with mercuric oxide and water. They are crystalline bodies. When heated with hydrochloric acid they yield cyanuric esters and ammonium chloride (B. **18**, 2784).

Trimethyl Isomelamine, $C_3N_3(CH_3)_3(NH)_3+3H_2O$, m.p. 179°, anhydrous. It already sublimes at about 100°. *Triethyl Isomelamine*, $C_3N_3(C_2H_5)_3(NH)_3+4H_2O$, consists of very soluble needles. Consult *Hofmann*, B. **18**, 3217, for the phenyl derivatives of the mixed melamines (also amide and imide bodies).

Cyanuramine Chlorides.

Cyanuramine Dichloride, $C_3N_3Cl_2(NH_2)$, corresponds with cyanuric monamide or ammelide (p. 473) or melanurenic acid; and *Cyanurodiamine Monochloride*, $C_3N_3Cl(NH_2)_2$, with cyanuric diamide or ammeline. The former substance is formed by the action of ammonia on an ethereal solution of cyanuric chloride; the latter by aqueous ammonia on the chloride. Similar conditions of experiment applied to methylamine and ethylamine give rise to the following substances: *Cyanuromethylamine Dichloride*, $C_3N_3Cl_2(NHCH_3)$, m.p. 161°; *Cyanuroethylamine Dichloride*, $C_3N_3Cl_2(NHC_2H_5)_2$, m.p. 107°, *Cyanuraminomethylamine Chloride*, $C_3N_3Cl(NH_2)(NHCH_3)$; *Cyanuraminoethylamine Chloride*, C_3N_3Cl-$NH(C_2H_5)(NH_2)$, m.p. 176°; *Cyanuromethylaminoethylamine Chloride*, C_3H_3Cl-$(NHCH_3)(NHC_2H_5)$, m.p. 235°. Ethylamine, methylamine and ammonia convert the three last-named chlorides into methyl ethyl melamine.

Cyanuramine Hydrides, Guanamines. The hydrogen compound, *hydrocyanuric acid* or *trihydrocyanic acid*,  $HC{<}{\genfrac{}{}{0pt}{}{N—CH}{N=CH}}{>}N$, corresponding with cyanuric chloride, is unknown. However, reduction of cyanuramine dichloride forms *Monaminohydrocyanuric Acid*, $C_3N_3H_2.NH_2$, m.p. 225°, whilst cyanodiamine monochloride yields *diaminohydrocyanuric acid*. *Guanamines* are the bases formed when fatty acid guanidine salts are heated to 220°–230°, whereby water and ammonia are driven off (*Nencki*, B. **9**, 228). The simplest guanamine is formed when guanidine formate is heated, or when biguanide (p. 457) is acted on by chloroform and potassium hydroxide solution (B. **25**, 535). This *Formoguanamine*,  $HC{<}{\genfrac{}{}{0pt}{}{N=C(NH_2)}{N—C(NH_2)}}{>}N$, m.p. 325°, is identical with *diaminohydrocyanuric acid* (see above). Homologous guanamines are derived from this, by the replacement of the H-atoms in the CH- group by alcohol radicals.

Acetoguanamine,  $CH_3C{<}{\genfrac{}{}{0pt}{}{N=C(NH_2)}{N—C(NH_2)}}{>}H$, m.p. 265°, is produced from guanidine acetate. Concentrated sulphuric acid at 150° converts it into acetoguanamide (comp. Acetyl Urethane, p. 436).

Ketenes, *Carbomethenes*, discovered by *Staudinger* in 1905, show a great similarity to the derivatives of isocyanic acid or the carbimides, such as alkyl isocyanates and acyl isocyanates (pp. 461, 462). By analogy to carbimides, they can be called carbomethenes:

$CO{=}NCH_3$	$CO{=}CH_2$
Methyl Isocyanate	Ketene
Carbo-methylimide.	Carbo-methene.

The ketenes can also be considered as *internal anhydrides* of monocarboxylic acids, and are then comparable with carbon monoxide (p. 267).

They are prepared (1) by the action of zinc on α-bromo-fatty acid bromides in indifferent solvents:

$$CH_2Br{-}COBr \xrightarrow{Zn} CH_2{=}CO + ZnBr_2$$

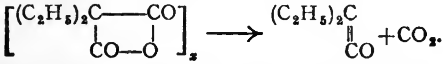
$$(CH_3)_2CBr{-}CBr \xrightarrow{Zn} (CH_3)_2C{=}CO + ZnBr_2.$$

Also, by the action of tertiary amines, such as triethylamine, on carboxylic acid chlorides, whereby hydrochloric acid is split off, ketenes probably are formed, but they polymerize instantaneously (see below).

(2) When the vapours of acetic anhydride are passed over a platinum wire heated electrically to redness, or through an electric arc, ketenes are formed:

$$CH_3CO.O.COCH_3 \longrightarrow 2CH_2{=}CO + H_2O.$$

(3) By heating dialkyl malonic anhydride (B. **41**, 2208):



$$\left[\begin{array}{l}(C_2H_5)_2C{-}CO \\ \quad\;\; | \qquad | \\ \quad\;\; CO{-}O\end{array}\right]_2 \longrightarrow \begin{array}{l}(C_2H_5)_2C \\ \qquad\quad \| \\ \qquad\quad CO\end{array} + CO_2.$$

Up to the present time the following members have been prepared: *Ketene, carbomethene*, $CH_2:CO$, m.p. −151°, b.p. −56°, a colourless, poisonous liquid, having an odour of chlorine and acetic anhydride. *Methyl Ketene, Carbomethyl Methene, Carboethylidene*, $CH_3CH:CO$, and *Ethyl Ketene, Carboethyl Methene, Carbopropylidene*, $C_2H_5CH:CO$, have only been obtained in ethereal solution.

Dimethyl Ketene, Carbodimethyl Methene, Carboisopropylene, $(CH_3)_2C{:}CO$ (comp. p. 290), m.p. −97·5°, b.p. 34°, is a very mobile, wine-yellow liquid. *Diethyl ketene*, $(C_2H_5)_2C_3CO_2$, b.p. 92°, is a yellow liquid.

Reactions.—The lower members are only stable at low temperatures, but somewhat more so in solution. They polymerize with extraordinary ease spontaneously or under the influence of zinc bromide or tertiary amines. Ketene gives rise to ***dehydracetic acid***, and dimethyl ketene to ***tetramethyl-cyclobutane-dione***:

$$4CH_2{:}CO \xrightarrow{(C_2H_5)_3N} C_8H_8O_4, \quad (CH_3)_2C:CO \longrightarrow (CH_3)_4C_4O_2.$$

The ketenes show none of the characteristic ketone reactions. Like the carbimides, they easily combine with water to form carboxylic acids or anhydrides; with alcohols to carboxylic esters, with ammonia or amines to carboxylic acid amides:

$$CH_3N{=}CO \xrightarrow{H_2O} CH_3NHCOOH, \text{ etc.} \qquad CH_2{=}CO \xrightarrow{H_2O} CH_3COOH$$

$$CH_3N{=}CO \xrightarrow{CH_3OH} CH_3NHCOOCH_3 \qquad CH_2{=}CO \xrightarrow{C_5H_{11}OH} CH_3COOC_5H_{11}$$

$$CH_3N{=}CO \xrightarrow{NH_3} CH_3NHCONH_2 \text{ (p. 461)}, \; CH_2{=}CO \xrightarrow{NH_3} CH_3CO.NH_2.$$

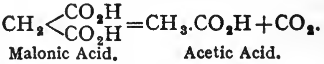
Bromine is taken up to form α-bromo-fatty acid bromides.

In contradistinction to the lower ketenes, dimethyl ketene combines with tertiary amines, such as pyridine, quinoline, etc., to form stable bodies, $C_5H_5N[(CH_3)_2C{:}CO]_2$, an oil; $C_9H_7[(CH_3)_2C:CO]_2$, m.p. 83°, which, when boiled with hydrochloric acid, form complex intermediate compounds and ultimately break down into the amine and isobutyric acid. Stable compounds are also formed with substances possessing the group $-C{=}N-$ (isocyanates, mustard oils, *Schiff's* bases). Oxygen is absorbed to form a very explosive peroxide (A. **356**, 51; B. **41**, 1025). Closely connected with the ketenes is *carbon suboxide*, C_3O_2, obtained from malonic acid and described with it (p. 487). See also ***diphenyl ketene*** and ***diphenylene ketene*** (Vol. II.).

10. DIBASIC ACID, DICARBOXYLIC ACIDS

A. PARAFFIN DICARBOXYLIC ACIDS, OXALIC ACID SERIES, $C_nH_{2n-2}O_4$, $C_nH_{2n}(CO_2H)_2$

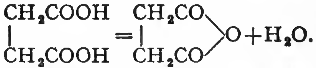
The acids of this series contain two carboxyl groups, and are therefore *dibasic*. They differ very markedly from each other on the application of heat, depending upon the position of the carboxyl groups. *Oxalic acid*, $CO_2H.CO_2H$, the first member of the series, breaks down on heating chiefly into CO_2, CO and water, and in part into CO_2 and formic acid. The nature of the latter decomposition is characteristic of all those homologues of oxalic acid, in which the two carboxyls are attached to the same carbon atom—the β-dicarboxylic acids, *e.g.* malonic acid, $CH_2(CO_2H)_2$. The latter acid and all *mono-* and *di-alkyl* malonic acids decompose on heating at the ordinary pressure into acetic acid (also mono- and di-alkyl acetic acids) with the elimination of CO_2. Malonic acid is the type of these acids:



$$CH_2{<}\begin{matrix}CO_2H\\CO_2H\end{matrix} = CH_3.CO_2H + CO_2.$$

Malonic Acid. Acetic Acid.

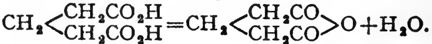
On the other hand, when the two carboxyl groups are attached to adjacent carbon atoms, as in ordinary or ethylene succinic acid, $CO_2H.CH_2CH_2.CO_2H$, and in the alkyl ethylene succinic acids, these γ-dicarboxylic acids, when heated, do not give up CO_2, but part with water and pass into *anhydrides*, which can also be prepared in other ways, whereas the anhydrides of the malonic acids are not known (p. 488). Ethylene succinic acid is the type of these acids:



$$\begin{matrix}CH_2COOH\\|\\CH_2COOH\end{matrix} = \begin{matrix}CH_2CO\\|\\CH_2CO\end{matrix}{>}O + H_2O.$$

Ethylene Succinic Acid. Succinic Anhydride.

Glutaric acid, or normal pyrotartaric acid, $CO_2H.CH_2.CH_2.CH_2.CO_2H$, in which the two carboxyl groups are attached to two carbon atoms, separated by a third, behaves in this manner. Like succinic acid, it yields a corresponding anhydride when it is heated. All acids, which can be regarded as alkyl glutaric acids, behave analogously:



$$CH_2{<}\begin{matrix}CH_2CO_2H\\CH_2CO_2H\end{matrix} = CH_2{<}\begin{matrix}CH_2CO\\CH_2CO\end{matrix}{>}O + H_2O.$$

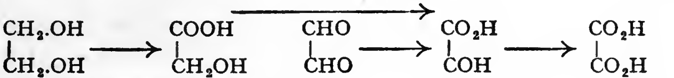
Glutaric Acid. Glutaric Anhydride.

When the carbon atoms, carrying the carboxyl groups, are separated by two carbon atoms from each other—*e.g.* adipic acid, $CO_2H.CH_2.CH_2.CH_2.CH_2.CO_2H$—they do not influence one another on the application of heat. Adipic acid volatilizes undecomposed.

Therefore, the numerous paraffin dicarboxylic acids are arranged in different groups, and, after oxalic acid, the malonic acid group, the succinic acid group, and the glutaric acid group will be discussed. Then will follow adipic acid, suberic acid, sebacic acid and others which do not belong to any one of the three acid groups mentioned above.

Formation.—The most important general methods are—

(1) Oxidation of (*a*) diprimary glycols, (*b*) primary hydroxyaldehydes, (*c*) dialdehydes, (*a*) primary hydroxyacids, and (*e*) aldehyde acids (p. 400):

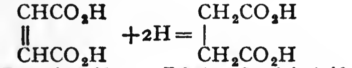


$$\begin{tikzcd} \begin{array}{l}CH_2.OH\\|\\CH_2.OH\end{array} \arrow[r] \arrow[rr, bend right] & \begin{array}{l}COOH\\|\\CH_2OH\end{array} \arrow[rr, bend left] & \begin{array}{l}CHO\\|\\CHO\end{array} \arrow[r] & \begin{array}{l}CO_2H\\|\\COH\end{array} \arrow[r] & \begin{array}{l}CO_2H\\|\\CO_2H\end{array} \end{tikzcd}$$

Glycol. Glycollic Acid. Glyoxal. Glyoxylic Acid. Oxalic Acid.

The dibasic acids are also formed when the fatty acids, $C_nH_{2n}O_2$, and the acids of the oleic acid series, as well as the fats, are oxidized by nitric acid. Certain hydrocarbons, C_nH_{2n}, have also been converted into dibasic acids by the action of potassium permanganate.

(2) By the reduction of unsaturated dicarboxylic acids:



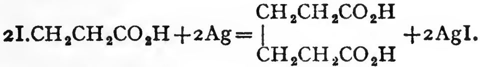
$$\begin{array}{l}CHCO_2H\\\|\\CHCO_2H\end{array} + 2H = \begin{array}{l}CH_2CO_2H\\|\\CH_2CO_2H\end{array}$$

Fumaric Acid. Ethylene Succinic Acid.

(3) When hydroxydicarboxylic acids and halogen dicarboxylic acids are reduced.

Nucleus-synthetic Methods of Formation.—These are very numerous.

(4) When silver in powder form (B. **2**, 720) acts on mono-iodo (or bromo-) fatty acids:

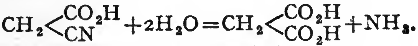


$$2I.CH_2CH_2CO_2H + 2Ag = \begin{array}{l}CH_2CH_2CO_2H\\|\\CH_2CH_2CO_2H\end{array} + 2AgI.$$

β-Iodopropionic Acid. Adipic Acid.

See *trialkyl-glutaric acids* for the abnormal course of this reaction when α-bromisobutyric acid is used.

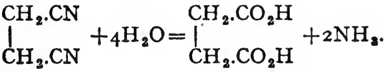
(5*a*) Conversion of monohalogen substituted fatty acids into cyanderivatives, and boiling the latter with alkalis or acids (pp. 252 and 280):



$$CH_2{<}\begin{array}{l}CO_2H\\CN\end{array} + 2H_2O = CH_2{<}\begin{array}{l}CO_2H\\CO_2H\end{array} + NH_3.$$

Cyanacetic Acid. Malonic Acid.

(5*b*) Conversion of the halogen addition products of the alkylenes, C_nH_{2n}, into cyanides and the saponification of the latter:



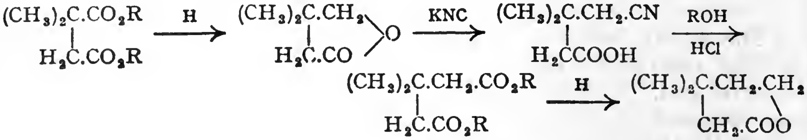
$$\begin{array}{l}CH_2.CN\\|\\CH_2.CN\end{array} + 4H_2O = \begin{array}{l}CH_2.CO_2H\\|\\CH_2.CO_2H\end{array} + 2NH_3.$$

Only the halogen products having their halogen atoms attached to two different carbon atoms can be converted into dicyanides.

Since dicarboxylic acids or their esters or anhydrides can be reduced to hydroxycarboxylic acids or their lactones (p. 372) by means of nascent hydrogen (from sodium and alcohol, electrolysis, etc.), and these can be converted into cyanocarboxylic acids, *viâ* halogen-carboxylic acids, it follows that these processes provide a means for the synthesis of progressively higher members of the dicarboxylic acid series:

$$\begin{array}{l}CO_2H.CO_2H \longrightarrow CH_2OH.CO_2H \longrightarrow CH_2ClCO_2H \longrightarrow CN.CH_2CO_2H\\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \longrightarrow CO_2H.CH_2CO_2H.\end{array}$$

(5*c*) γ- and *d*-Lactones, when heated with potassium cyanide and subsequently hydrolyzed, are converted directly into a higher acid (comp. p. 373) (C. 1905, II. 755):

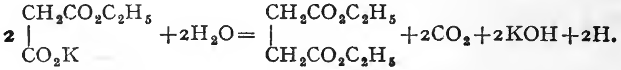


$$\begin{array}{l}(CH_3)_2C.CO_2R\\ \quad |\\ H_2C.CO_2R\end{array} \xrightarrow{H} \begin{array}{l}(CH_3)_2C.CH_2\diagdown\\ \quad | \qquad\qquad\quad >O\\ H_2C.CO\ \diagup\end{array} \xrightarrow{KNC} \begin{array}{l}(CH_3)_2C.CH_2.CN\\ \quad |\\ H_2CCOOH\end{array} \xrightarrow[HCl]{ROH}$$

$$\begin{array}{l}(CH_3)_2C.CH_2.CO_2R\\ \quad |\\ H_2C.CO_2R\end{array} \xrightarrow{H} \begin{array}{l}(CH_3)_2C.CH_2.CH_2\\ \quad | \qquad\qquad\qquad \diagdown\\ CH_2.COO\end{array}$$

(6) In the synthesis of the mono- and di-alkyl malonic acids it is of the first importance to replace the hydrogen atoms of the CH_2 group of the malonic acid in its esters by alkyl groups, just as was done in the case of acetoacetic ester (p. 413). This reaction will be more fully developed in the malonic acid group (p. 487).

(7) By the electrolysis of concentrated solutions of the potassium salts of the dicarboxylic acids mono-alkyl esters (see electrolysis of the mono-carboxylic acids (pp. 73, 83, 253):

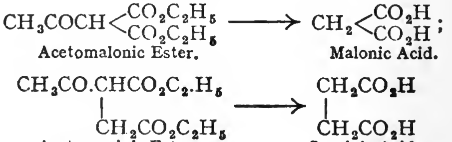


$$2\begin{array}{l}CH_2CO_2C_2H_5\\ |\\ CO_2K\end{array}+2H_2O=\begin{array}{l}CH_2CO_2C_2H_5\\ |\\ CH_2CO_2C_2H_5\end{array}+2CO_2+2KOH+2H.$$

Potassium Ethyl Malonate.

Succinic Ethyl Ester.

(8) A very general method for the synthesis of dibasic acids is based upon the decomposition of β-ketone dicarboxylic esters. Acid residues are introduced into the latter and the products decomposed by concentrated alkali solutions (p. 415):



$$CH_3COCH<\begin{array}{l}CO_2C_2H_5\\ CO_2C_2H_5\end{array} \longrightarrow CH_2<\begin{array}{l}CO_2H\\ CO_2H\end{array};$$

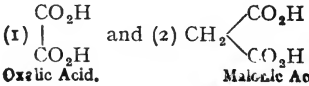
Acetomalonic Ester. Malonic Acid.

$$\begin{array}{l}CH_3CO.CHCO_2C_2.H_5\\ \qquad |\\ \qquad CH_2CO_2C_2H_5\end{array} \longrightarrow \begin{array}{l}CH_2CO_2H\\ |\\ CH_2CO_2H\end{array}$$

Acetosuccinic Ester. Succinic Acid.

(9) Tricarboxylic acids, containing two carboxyl groups attached to the same C-atom, split off CO_2 and yield the dibasic acid. Ethane tricarboxylic acid yields succinic acid, and isobutane tricarboxylic acid gives rise to unsym.-dimethyl succinic acid, etc.

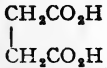
Isomerism.—The possible structural isomers of the dicarboxylic acids depend upon whether the two COOH groups are attached to two different carbon atoms or to a single atom. Isomers of the first two members of the series—



$$(1)\begin{array}{l}CO_2H\\ |\\ CO_2H\end{array} \text{ and } (2)\ CH_2<\begin{array}{l}CO_2H\\ CO_2H\end{array}$$

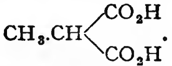
Oxalic Acid. Malonic Acid.

are not possible. For the third member two structural cases exist:

(3) 

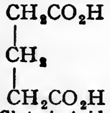
$$\begin{array}{l}CH_2CO_2H\\ |\\ CH_2CO_2H\end{array}$$

Ethylene Dicarboxylic Acid,
Succinic Acid.

and 

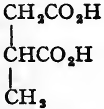
Ethylidene Dicarboxylic Acid,
Isosuccinic Acid.

There are four possible isomers with the formula $C_3H_6{<}\begin{smallmatrix}CO_2H\\ CO_2H\end{smallmatrix}$, etc.; all are known:

(4) 

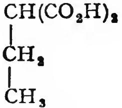
$$\begin{array}{l}CH_2CO_2H\\ |\\ CH_2\\ |\\ CH_2CO_2H\end{array}$$

Glutaric Acid,
n-Pyrotartaric Acid.



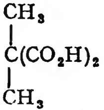
$$\begin{array}{l}CH_2CO_2H\\ |\\ CHCO_2H\\ |\\ CH_3\end{array}$$

Ord. Pyrotartaric
Acid.



$$\begin{array}{l}CH(CO_2H)_2\\ |\\ CH_2\\ |\\ CH_3\end{array}$$

Ethyl Malonic
Acid.



$$\begin{array}{l}CH_3\\ |\\ C(CO_2H)_2\\ |\\ CH_3\end{array}$$

Dimethyl Malonic
Acid.

(5) The fifth member of the series, the acid $C_4H_8(CO_2H)_2$, has nine possible isomers; all are known:

(*a*) Adipic acid—$CO_2H[CH_2]_4CO_2H$.

(*b*) α- and β-Methyl glutaric acid.

(*c*) Sym.- and unsym.-dimethyl succinic acid, and ethyl succinic acid.

(*d*) Propyl, isopropyl, and methyl ethyl malonic acids.

(6) There are twenty-four imaginable isomers of the sixth member—the acids $C_5H_{10}(CO_2H)_2$ (A. **292**, 134).

Nomenclature (p. 42).—Whilst the names of the older dicarboxylic acids—*e.g.* oxalic, malonic, succinic, etc.—recall the occurrence or the methods of making these acids, the names of those acids which have been synthetically prepared from malonic esters are derived from malonic acid, *e.g. methyl malonic acid, dimethyl malonic acid.* The names of the *alkyl ethylene succinic acids*, etc., have been derived from ethylene succinic acid.

The "Geneva names" are deduced, like those for the monocarboxylic acids, from the corresponding hydrocarbons; oxalic acid=[Ethane-diacid]; malonic acid=[Propane-diacid]; ethylene succinic acid=[Butane-diacid]. The bivalent residues linked to the two hydroxyls are called the *radicals* of the dicarboxylic acids—*e.g.* CO.CO, *oxalyl;* $CO.CH_2.CO$, *malonyl*, and $CO.CH_2.CH_2.CO$, *succinyl.* The *melting points* of the normal dicarboxylic acids exhibit great regularity: the members containing an even number of carbon atoms melt higher than those with an odd number (*Baeyer*, p. 62).

Derivatives of the Dicarboxylic Acids—It has been indicated in connection with the monocarboxylic acids (p. 233) what derivatives of an acid can be obtained by a change in the carboxyl group. As might well be expected, the derivatives of the dicarboxylic acids are much more numerous, because not only the one group, but both carboxyls can take part in the reaction. The *heterocyclic derivatives* of the ethylene succinic and glutaric acid groups are particularly noteworthy: they are the *anhydrides* (p. 476) and the *acid imides, e.g. succinimide,* $\begin{array}{l}CH_2.CO\\ |\\ CH_2.CO\end{array}{>}NH$, and *glutarimide,* $CH_2{<}\begin{smallmatrix}CH_2.CO\\ CH_2.CO\end{smallmatrix}{>}NH$. They have been previously mentioned.

OXALIC ACID AND ITS DERIVATIVES

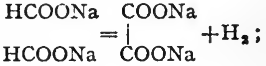
(1) **Oxalic Acid**, [Ethane-diacid], $C_2O_4H_2$ (*Acidum oxalicum*), m.p. anhydrous, 189°, hydrated, 101°, if rapidly heated (B. **21,** 1901), occurs in many plants, chiefly as potassium salt in the different varieties of *Oxalis* and *Rumex*. The calcium salt is often found crystallized in plant cells; it constitutes the chief ingredient of certain calculi.

The acid may be prepared artificially (1) by oxidizing many carbon compounds, such as sugar, starch, etc., with nitric acid.

Frequent mention has been made of its formation in the oxidation of glycol, glyoxal, glycollic acid and glyoxylic acid (pp. 312, 477).

(2) From cellulose: by fusing sawdust with potassium hydroxide in iron pans at 200–220°. The fused mass is extracted with water, precipitated as calcium oxalate, and this is then decomposed by sulphuric acid (technical method).

(3) It is formed synthetically by (*a*) rapidly heating sodium formate above 440° (B. **15,** 4507): the addition of sodium hydroxide, carbonates or oxalates enable the reaction to take place at 360°, and more completely (C. 1903, II. 777; 1905, II. 367):



$$\begin{matrix}HCOONa\\HCOONa\end{matrix} = \begin{matrix}COONa\\|\\COONa\end{matrix} + H_2;$$

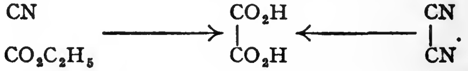
by (*b*) oxidizing formic acid with nitric acid (B. **17,** 9).

(4) By conducting *carbon dioxide* over metallic sodium heated to 350–360° (A. **146,** 140):

$$2CO_2+Na_2=C_2O_4Na_2.$$

CO_2 and potassium hydride yield a mixture of potassium formate (p. 237) and oxalate.

(5) Upon treating the *nitriles*, cyanocarbonic ester and dicyanogen, with hydrochloric acid or water respectively:



$$\begin{matrix}CN\\CO_2C_2H_5\end{matrix} \longrightarrow \begin{matrix}CO_2H\\|\\CO_2H\end{matrix} \longleftarrow \begin{matrix}CN\\|\\CN\end{matrix}.$$

History.—At the beginning of the seventeenth century salt of sorrel was known, and was considered to be a variety of argol. *Wiegleb* (1778) recognized the peculiarity of the acid contained in it. *Scheele* had obtained the free oxalic acid as early as 1776 by oxidizing sugar with nitric acid, and showed in 1784 that it was identical with the acid of the salt of sorrel. *Gay-Lussac* (1829) discovered that oxalic acid was formed by fusing cellulose, sawdust, sugar, etc., with potassium hydroxide. This process was introduced into practical manufacture in 1856 by *Dale*.

Constitution.—Free oxalic acid crystallizes with two molecules of water. The crystallized acid is probably *ortho-oxalic acid,* $C(OH)_3.C(OH)_3$ (p. 235). Ortho-esters of the acid $C_2(OR')_6$ are not known, but esters do exist, which are derived from the non-isolated *half-ortho-oxalic acid,* $C(OH)_3.CO_2H$.

Properties and Reactions.—Oxalic acid crystallizes in monoclinic prisms, which effloresce at 20° in dry air. Large quantities of the acid, introduced into the system, are poisonous. It is soluble in 9 parts of water at ordinary temperatures, and fairly easily in alcohol, and with difficulty in ether (C. 1897, I. 539). Anhydrous oxalic acid crystallizes from concentrated sulphuric and nitric acid (B. **27**, R. 80), and can be employed as a means of bringing about condensation, on account of its power of abstracting the elements of water from the substance to be condensed (B. **17**, 1078). When carefully heated to 150° the anhydrous acid sublimes undecomposed. (1) Rapidly heated it decomposes into formic acid and carbon dioxide, and also into CO_2, CO and water:

$$C_2H_2O_4 = CH_2O_2 + CO_2; \quad C_2H_2O_4 = CO_2 + CO + H_2O.$$

(2) An aqueous oxalic acid solution under the influence of light and air decomposes into CO_2, H_2O, and in the presence of sufficient oxygen, H_2O_2 (B. **27**, R. 496).

(3) Oxalic acid decomposes into carbonate and hydrogen by fusion with alkalis or soda lime:

$$C_2O_4K_2 + 2KOH = 2K_2CO_3 + H_2.$$

(4) Heated with concentrated sulphuric acid it yields carbon monoxide, dioxide and water.

(5) Nascent hydrogen converts it first into glyoxyllic acid (p. 400) and then into glycollic acid (p. 362).

(6) Concentrated nitric acid slowly oxidizes oxalic acid to CO_2 and water. However, potassium permanganate in acid solution rapidly oxidizes it, a reaction which is used in volumetric analysis.

Persulphates in acid solution and in presence of silver salts oxidize oxalic acid very energetically. This reaction constitutes a quantitative method for determining the active oxygen of persulphates (B. **38**, 3963).

A solution of mercuric chloride and ammonium oxalate rapidly decomposes, in the light and in absence of oxygen, into carbon dioxide and calomel (B. **38**, 2602).

(7) PCl_5 changes oxalic acid into $POCl_3$, CO_2, CO, and 2HCl. It has also been possible to replace 2Cl by O in certain organic dichlorides by using anhydrous oxalic acid (p. 272). $SbCl_5$, however, and oxalic acid yield the compound $(COOSbCl_4)_2$ (A. **239**, 285; **253**, 112; B. **35**, 1119).

The *oxalates*, excepting those with the alkali metals, are almost insoluble in water.

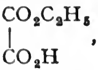
Di-potassium Oxalate, $C_2O_4K_2 + H_2O$. *Mono-potassium Oxalate*, C_2O_4HK, dissolves with more difficulty than the neutral salt, and occurs in the juices of plants, such as *Oxalis* and *Rumex*. *Potassium Peroxalate*, $C_2O_4KH.C_2O_4H_2 + 2H_2O$.

Di-ammonium Oxalate, $C_2O_4(NH_4)_2 + H_2O$, consists of shining, rhombic prisms, which occur in lævo- and dextro-*hemihedral crystals* (B. **18**, 1394; C. 1905, II. 885). *Calcium Oxalate*, $C_2O_4Ca + H_2O$, is insoluble in acetic acid, and serves for the detection of calcium and of oxalic acid, both of which are determined quantitatively in this form. The *silver salt*, $C_2O_4Ag_2$, explodes when quickly heated.

Oxalic acid yields crystalline compounds with substances containing oxygen, such as cinnamic aldehyde, cineol, and dimethyl pyrone (Vol. II.) (B. **35**, 1211).

Trimercuric Acetic Acid, $HOHg(Hg_2O)C.COOH$, and *Mercarbide*, $HOHg\text{-}(Hg_2O)C.C(Hg_2O)HgOH$ (comp. p. 116), are derivatives of oxalic acid. They are obtained when acetic acid or alcohol is heated with HgO in the presence of alkalis. They consist of white powders of basic character. Mercarbide is very stable towards reagents, but explodes violently when heated above 200° (B. **33**, 1328; **36**, 3707; **38**, 3654).

Oxalic Esters.—The acid and neutral esters of oxalic acid are formed simultaneously when anhydrous oxalic acid is heated with alcohols. They are separated by distillation under reduced pressure (*Anschütz*, A. **254**, 1).

Oxalic Mono-ethyl Ester,  $\begin{array}{l}CO_2C_2H_5\\ |\\ CO_2H\end{array}$, b.p.$_{15}$ 117°; $D_{20}=1{\cdot}2175$. *Oxalic n.-Propyl Ester*, $CO_2.C_3H_7.CO_2H$, b.p.$_{12}$ 118°. Preserved in sealed tubes, the alkyl oxalic acids decompose into anhydrous oxalic acid and the neutral esters. Distilled at the ordinary temperature, they break down mainly into oxalic ester, CO_2, CO and H_2O, and in part to CO_2 and formic esters.

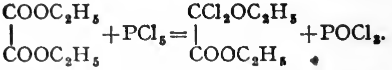
Oxalic Methyl Ester, $C_2O_4(CH_3)_2$, m.p. 54°, b.p. 153°.

Oxalic Ethyl Ester, b.p. 186°, is formed upon heating oxomalonic ester (B. **27**, 1304). See p. 427 for its conversion into carbonic ester. Oxalic ester, under the influence of sodium ethoxide, condenses with acetic ester to form oxalacetic ester, $CO_2C_2H_5.CO.CH_2.CO_2C_2H_5$, and with acetone to acetone oxalic ester comp. (*chelidonic acid*). Zinc and alkyl iodides convert the oxalic ester into dialkyl oxalic esters (p. 358).

Oxalic ester unites with hydroferrocyanic acid to form a well-crystallizing compound $(COOC_2H_5)_2.H_4Fe(CN)_6$ (B. **34**, 2692). With $SbCl_5$ ethyl oxalate forms $Cl_4SbC_2H_4OCO.COOC_2H_3(SbCl_4)_2$ (B. **35**, 1120).

Ethylene Oxalic Ester,  $\begin{array}{ll}COOCH_2\\ | & |\\ COOCH_2\end{array}$, m.p. 143°, b.p.$_9$ 197° (B. **27**, 2941).

Half-ortho-oxalic Acid Derivatives.—*Dichloroxalic Esters*: When PCl_5 acts on the neutral oxalic esters, one of the doubly-linked oxygen atoms is replaced by 2Cl atoms:



$$\begin{array}{l}COOC_2H_5\\ |\\ COOC_2H_5\end{array}+PCl_5=\begin{array}{l}CCl_2OC_2H_5\\ |\\ COOC_2H_5\end{array}+POCl_3.$$

These products are called dichloroxalic esters (B. **28**, 61, note). When fractionated under greatly reduced pressure, they can be separated from unaltered oxalic ester. Distilled at the ordinary pressure, these esters decompose into alkyl chlorides and alkyl oxalic acid chlorides (see below).

Dichloroxalic Dimethyl Ester, $CCl_2(OCH_3).CO_2CH_3$, b.p.$_{12}$ 72°. $D_{20}=1{\cdot}3591$. *Dichloroxalic Diethyl Ester,* b.p.$_{10}$ 85°. *Dichloroxalic Di-n-Propyl Ester,* b.p.$_{10}$ 107°.

Ethyl Dichloroxalic Chloride, $COCl.CCl_2.OC_2H_5$, b.p. 140°, results from trichlorovinyl ethyl ether, $CCl_2{:}\ CClOC_2H_5$, by absorption of oxygen (A. **308**, 324).

Half-ortho-oxalic Esters are produced by the interaction of dichloroxalic esters with sodium alcoholates in ether:

$$CO_2C_2H_5.CCl_2OC_2H_5+2C_2H_5ONa=CO_2C_2H_5.C(OC_2H_5)_3+2NaCl.$$

Tetramethyl Oxalic Ester, $C(OCH_3)_3.COOCH_3$, b.p.$_{12}$ 76°; $D=1{\cdot}1312$. *Tetraethyl Oxalic Ester,* b.p.$_{12}$ 98° (A. **254**, 31).

The anhydride of oxalic acid is not known. In attempting to prepare it CO_2 and CO are produced. However, the chlorides of the alkyl oxalic acids, and probably oxalyl chloride, are known.

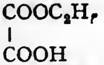
Chlorides of Alkyl Oxalic Acid are obtained by the action of $POCl_3$ on potassium alkyl oxalates, and of $SOCl_2$ on alkyl oxalic acids (B. **37**, 3678). It is most practically prepared by boiling dichloroxalic esters under the ordinary pressure until the evolution of the alkyl chloride ceases (A. **254**, 26). They show the reactions of an acid chloride (p. 269). With benzene hydrocarbons and Al_2Cl_6 they yield phenyl glyoxylic esters and their homologues (B. **14**, 1689; **29**, R. 511, 546; C. 1897, I. 407).

Methyl Oxalic Chloride, $COCl.CO_2CH_3$, b.p. 119°; $D_{20}=1{\cdot}3316$. *Ethyl Oxalic Chloride,* $COCl.CO_2C_2H_5$, b.p. 135°; $D=1{\cdot}2223$. n-*Propyl Oxalic Chloride,* b.p. 153°. *Isobutyl Oxalic Chloride,* b.p. 164°. *Amyl Oxalic Chloride,* b.p. 184°. These are liquids with a penetrating odour. *Oxalic Mono-ethyl Ester Anhydride,* $(C_2H_5OCO.CO)_2O$, b.p.$_{100}$ 135°, is prepared by heating ethyl oxalic chloride and sodium acetate together, and fractionating the product of reaction (C. 1900, II. 174).

Oxalyl Chloride, $C_2O_2Cl_2$ (?), b.p. 70°. It has not been obtained free from $POCl_3$. It is said to be formed when three molecules of phosphorus pentachloride act on $(COOC_2H_5)_2$ (B. **25**, R. 110).

AMIDES OF OXALIC ACID

Oxalic acid yields two amides: *oxamic acid,* corresponding with the mono-ethyl oxalic ester, and *oxamide,* corresponding with oxalic diethyl ester. *Oximide* can be included with these:

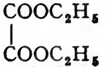


$\begin{matrix}COOC_2H_5\\|\\COOH\end{matrix}$

Ethyl Oxalic Acid.

$\begin{matrix}CO.NH_2\\|\\COOH\end{matrix}$

Oxamic Acid.



$\begin{matrix}COOC_2H_5\\|\\COOC_2H_5\end{matrix}$

Oxalic Ester.

$\begin{matrix}CONH_2\\|\\CONH_2\end{matrix}$

Oxamide.

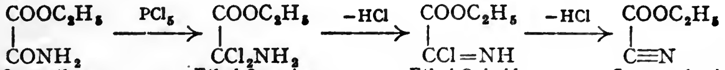
$\begin{matrix}CO\\|\\CO\end{matrix}>NH$ (?).

Oximide.

Oxamic Acid, $C_2O_2<\begin{matrix}NH_2\\OH\end{matrix}$, m.p. 210° with decomposition. Its ammonium salt (*Balard,* 1842) is produced (1) by heating ammonium hydrogen oxalate; (2) from oxamide; (and (3) by boiling oxamic acid esters with ammonia (B. **19,** 3229; **22,** 1569). Hydrochloric acid precipitates oxamic acid from its ammonium salt as a difficultly soluble crystalline powder.

Its *esters* result from the action of alcoholic or dry ammonia on the esters of oxalic acid:

Ethyl Oxamic Ester, Oxamethane, $CONH_2.COOC_2H_5$, m.p. 114° (*Boullay* and *Dumas,* 1828). The behaviour of oxamethane towards PCl_5 is important theoretically, because at first it yields *ethyl oxamino-chloride, oxamethane chloride,* a derivative of half-ortho-oxalic acid (comp. Dichloroxalic Ester, p. 482). This splits off a molecule of HCl and becomes ethyl oximido-chloride, and by the loss of a second molecule of HCl passes into *cyanocarbonic ester* (p. 484) (*Wallach,* A. **184,** 1):



$$\begin{matrix}COOC_2H_5\\|\\CONH_2\end{matrix}\xrightarrow{PCl_5}\begin{matrix}COOC_2H_5\\|\\CCl_2NH_2\end{matrix}\xrightarrow{-HCl}\begin{matrix}COOC_2H_5\\|\\CCl{=}NH\end{matrix}\xrightarrow{-HCl}\begin{matrix}COOC_2H_5\\|\\C{\equiv}N\end{matrix}$$

Oxamethane. Ethyl Oxamino-chloride. Ethyl Oximido-chloride. Cyanocarbonic Ester.

Oxamine Trimethyl Ortho-Ester, $CONH_2.C(OCH_3)_3$, m.p. 115°, is formed on heating half-ortho-oxalic methyl ester with anhydrous methyl alcoholic ammonia.

Methyl Oxamic Acid, $CONH(CH_3).CO_2H$, m.p. 146°.

Ethyl Oxamic Acid, $CONH(C_2H_5)CO_2H$, m.p. 120°.

Diethyl Oxamic Acid, Diethyl Oxamethane, $CON(C_2H_5)_2CO_2H$, b.p. 254°, is produced by the action of diethylamine on oxalic esters. It regenerates diethylamine on being distilled with potassium hydroxide. A method for separating the amines (p. 161) is based on this behaviour.

Oxanilic Acid (see Vol. II.).

Oxalimide, $\begin{matrix}CO\\|\\CO\end{matrix}>NH$ (?), is obtained from oxamic acid by the aid of PCl_5 or PCl_3O (B. **19,** 3229). The molecule is probably a double one.

Oxamide, $C_2O_2(NH_2)_2$, separates as a white, crystalline powder, when neutral oxalic ester is shaken with aqueous ammonia (1817, *Bauhof*). It is insoluble in water and alcohol. It is also formed on heating ammonium oxalate (1830, *Dumas;* 1834, *Liebig*); and when water and a trace of aldehyde act on cyanogen, C_2N_2; or by the direct union of hydrocyanic acid and hydrogen peroxide:

$$2HNC+H_2O_2=C_2O_2N_2H_4.$$

Oxamide is partially sublimed when heated, the greater part, however, being decomposed. When heated to 200° with water, it is converted into ammonium oxalate. P_2O_5 converts it into dicyanogen; concentrated sulphuric acid, into ammonium sulphate, CO_2 and CO (B. **39,** 57).

Alkyl oxamides are produced by the action of the primary amines on the oxalyl esters.

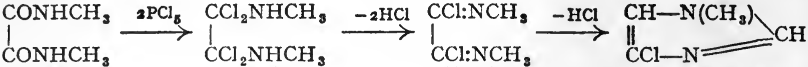
sym.-*Dimethyl Oxamide*, $(CONHCH_3)_2$, m.p. 210°.

sym.-*Diethyl Oxamide*, $(CONC_2H_5)_2$, m.p. 179°.

Tetramethyl Oxamide, $[CON(CH_3)_2]_2$, m.p. 80°, is obtained from dimethyl urea chloride by the action of sodium (B. **28**, R. 234).

Oxanilide (Vol. II.).

PCl_5 converts these alkyl oxamides into amide chlorides, which lose 3HCl and pass into *glyoxaline derivatives* (*Wallach*, A. **184**, 33; *Japp*, B. **15**, 2420): thus *diethyl oxamide* yields *chloroxalomethyline*, and diethyl oximide yields *chloroxalethyline*:



Dimethyl Oxamide. Dimethyl Oxamide Tetrachloride. Dimethyl Oximide Dichloride. Chloroxalmethylin.

Oxamidoacetic Acid, Amidoxolyl Glycocoll, $NH_2CO.CONH.CH_2CO_2H$, m.p. 224–228° with decomposition, and *Oxalyl Diglycocoll, Oxamidodiacetic Acid*, $CO_2HCH_2.NHCOCONH.CH_2CO_2H$, are formed from oxamethane and oxalic ester and glycocoll respectively (B. **30**, 580).

Diethyl Dinitro-oxamide, $\genfrac{}{}{0pt}{}{NO_2}{C_2H_5}{>}N.CO.CO.N{<}\genfrac{}{}{0pt}{}{NO_2}{C_2H_5}$, m.p. 35°, is decomposed by dilute sulphuric acid to form ethyl nitramine (C. 1898, I. 373).

Hydrazides and Hydroxyamides of Oxalic Acid, *Semi-oxamazide, Oxaminic Hydrazide*, $NH_2COCONH.NH_2$, m.p. 220° with decomposition, is prepared from oxamethane and hydrazine. Similarly to semicarbazide, it gives condensation products with aldehydes and ketones (B. **30**, 585).

Oxalic Hydrazide, $NH_2.NHCOCO.NHNH_2$, decomposes at about 235°, and turns brown. It is formed when hydrazine hydrate acts on oxalic ester. It unites with acetoacetic ester to form *bis-acetoacetic ester oxalhydrazone*, $(C_6H_{10}O_2):NNHCOCONHN:(C_6H_{10}O_2)$ (B. **40**, 711).

The reaction products of diazoacetic acid (p. 405) can be looked on as being cyclic hydrazine derivatives of oxalic acid; they yield hydrazine and oxalic acids when hydrolyzed.

Hydroxyl Oxamide, $NH_2COCONH.OH$, m.p. 159°, is formed from oxamethane and hydroxylamine.

Acetoxyl Oxamide, $NH_2COCONH.OCOCH_3$, m.p. 173°, when heated with acetic anhydride to 110° is decomposed into cyanuric acid (p. 463) and acetic acid (A. 288, 314; comp. C. 1901, II. 210, 402). *Amidoxime Oxalic Acid*, $HOOC.C(NOH)NH_2$ (A. **321**, 357).

NITRILES OF OXALIC ACID

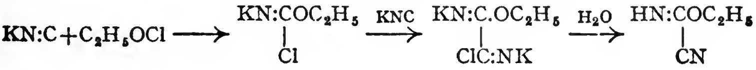
Two nitriles correspond with each dicarboxylic acid: a nitrilic acid, or a half-nitrile, and a dinitrile. The nitrilic acid of oxalic acid is *cyanocarbonic, cyanoformic*, or *oxalonitrilic acid*, and it is only known in its esters. Dicyanogen is the dinitrile of oxalic acid. The connection between these nitriles and oxalic acid is shown by their formation from the oxamic esters and oxamide through the elimination of water, and their conversion into oxalic acid by the absorption of water and the loss of ammonia:

$$\begin{array}{l}COOC_2H_5\\|\\CONH_2\end{array}\xrightarrow{-H_2O}\begin{array}{l}COOC_2H_5\\|\\CN\end{array}\qquad\begin{array}{l}CONH_2\\|\\CONH_2\end{array}\xrightarrow{-2H_2O}\begin{array}{l}CN\\|\\CN\end{array}$$

Oxamethane. Cyanocarbonic Ethyl Ester. Oxamide. Dicyanogen.

Cyanocarbonic Esters, *Cyanoformic Esters, Nitrilo-oxalic Esters*, are produced during the distillation of oxamic esters with P_2O_5 or PCl (p. 483), as well as from cyanimidocarbonic ether. *Cyanocarbonic Methyl Ester*, $CN.CO_2CH_3$, b.p. 100°. *Cyanocarbonic Ethyl Ester*, b.p. 115°. These are liquids with a penetrating odour. They are insoluble in water, which slowly decomposes them into CO_2, hydrocyanic acid, and alcohols. Zinc and hydrochloric acid convert them into *glycocoll* (p. 385). Concentrated hydrochloric acid breaks them down into *oxalic acid*, ammonium chloride, and alcohols. Bromine or gaseous HCl at 100° converts the ethyl ester into the polymeric cyanuric tricarboxylic esters (p. 465).

Cyanimidocarbonic Acid Ethers, Oxalic Nitrile Imido Ether, $CN.C({:}NH)OC_2H_5$, b.p.$_{30}$ 50°, is prepared from cyanogen chloride or bromide and water, alcohol, and potassium cyanide; also from potassium cyanide, water, and ethyl hypochlorite (p. 141), when the following intermediate compounds must be assumed:



$$KN{:}C+C_2H_5OCl \longrightarrow \underset{Cl}{\underset{|}{KN{:}COC_2H_5}} \xrightarrow{KNC} \underset{ClC{:}NK}{\underset{|}{KN{:}C.OC_2H_5}} \xrightarrow{H_2O} \underset{CN}{\underset{|}{HN{:}COC_2H_5}}$$

This reaction points to K.N:C being the formula for potassium cyanide, since it is hard to represent it with the formula KCN (A. **287**, 273). Cyanimidocarbonic acid ether forms a yellow, sweet oil, possessing, at the same time, a pungent odour. Concentrated hydrochloric acid converts it into ammonium chloride and cyanocarbonic acid ester.

Chlorethyl Imidoformyl Cyanide, Oxalic Nitrile Ethyl Imidochloride, $CN.C({:}NC_2H_5)Cl$, b.p. 126°, is prepared from cyanogen chloride and ethyl isocyanide (A. **287**, 302).

Cyanorthoformic Ester, Triethoxyacetonitrile, Ortho-oxalonitrilic Ethyl Ester, $CN.C(OC_2H_5)_3$, b.p. 160° (A. **229**, 178).

Trinitro-acetonitrile, $CNC(NO_2)_3$, m.p. 41·5°, explodes at 220° (see fulminuric acid, p. 250).

Dicyanogen, *Oxalonitrile*, [Ethane Dinitrile], CN.CN, b.p. −21°, D=0·866 (liquid), is present in small quantity in the gases of the blast furnace. It was obtained in 1815 by *Gay-Lussac* by the ignition of mercury cyanide. The change proceeds more readily by the addition of mercuric chloride:

$$Hg(CN)_2=C_2N_2+Hg. \quad Hg(CN)_2+HgCl_2=C_2N_2+Hg_2Cl_2.$$

Silver and gold cyanides behave similarly. Dicyanogen is most readily prepared from potassium cyanide, by adding gradually a concentrated aqueous solution of 1 part KNC to 2 parts cupric sulphate in 4 parts of water, and then heating. At first a yellow precipitate of copper cyanide, $Cu(CN)_2$, is produced, but it immediately breaks up into cyanogen gas and cuprous cyanide, CuCN (B. **18**, R. 321):

$$2CuSO_4+4KNC=Cu_2(CN)_2+(CN)_2+2K_2SO_4.$$

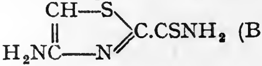
Its preparation by heating ammonium oxalate, and from oxamide and P_2O_5, is of theoretical interest.

Properties and Reactions.—Cyanogen is a colourless, peculiar-smelling, poisonous gas. It may be condensed to a mobile liquid at a temperature of −25°, or by a pressure of five atmospheres at ordinary temperatures; at −34° it forms a crystalline mass. It burns with a bluish, purple-mantled, flame. Water dissolves 4 volumes and alcohol 23 volumes of the gas.

On standing the solutions become dark and break down into ammonium oxalate and formate, hydrogen cyanide and urea, and at the same time a brown body, the so-called *azulmic acid*, $C_4H_5N_5O$, separates. With aqueous potassium hydroxide cyanogen yields potassium cyanide and isocyanate. In these reactions the molecule breaks down, and if a slight quantity of aldehyde be present in the aqueous solution, only oxamide results. Oxalic acid is produced in the presence of mineral acids, $C_2N_2+4H_2O=C_2O_4H_2+2NH_3$. When heated with concentrated hydriodic acid it is converted into glycocoll (p. 385). Cyanogen unites with acetyl acetone (p. 350), with sodium acetoacetic ester (p. 418), and with sodium malonic ester (p. 488).

Paracyanogen.—On heating mercuric cyanide there remains a dark substance, *paracyanogen*, a polymeric modification, $(C_2N_2)n$. Strong ignition converts it again into cyanogen. It yields potassium cyanate with potassium hydroxide.

Thioamides of Oxalic Acid. *Rubeanic Acid, Dithio-oxamide*, $CSNH_2.CSNH_2$, and *Flaveanic Acid, Cyanothioformamide*, $CS.NH_2.CN$, m.p. 87–89°, with decomposition, are formed when H_2S and cyanogen interact. They can be separated by means of chloroform, in which rubeanic acid is soluble with difficulty, and which deposits the flaveanic acid in the form of yellow, transparent, flat needles (A. **254**, 262). Rubeanic acid forms yellowish-red crystals. Primary bases cause the replacement of the amido-groups by alkyl amido-groups (A. **262**, 354). Aldehydes unite with rubeanic acid, with elimination of water (B. **24**, 1017). *Chrysean*, $C_4H_5N_3S_2$, is prepared from KNC and H_2S, or thioformamide, $HCSNH_2$, and probably possesses the formula



(B. **36**, 3546). *Thio-oxalic Acid*, HSCO.COSH (C. 1903, I. 816).

Diamido-oxalic Ethers result from the action of ammonia on dichloroxalic esters, but have not yet been obtained in a pure condition. Aniline and dichloroxalic ether in cold ethereal solution, yield *Dianilido-oxalic Ether*, $CO_2C_2H_5C(NHC_6H_5)_2OC_2H_5$, a thick liquid, soluble in ether. At 0° hydrochloric acid precipitates from this ethereal solution the hydrochloride, $CO_2C_2H_5C(NHC_6H_5\text{-}HCl)_2OC_2H_5$. Mixed diamido-ethers can be obtained by allowing anhydrous ammonia gas to act on a cooled, ethereal solution of monophenylimido-oxalic acid dimethyl ether. In this way *Amino-anilido-oxalic Methyl Ester*, $CO_2CH_3.C(NH_2)(NHC_6H_5)OCH_3$, is obtained, m.p. 215°.

Imido-oxalic Ethers: *Mono-imido-oxalic Ether*, $CO_2C_2H_5.C(:NH)OC_2H_5$, b.p.$_{18}$ 73°, results from the action of a calculated amount of $\frac{1}{10}$ *n*-hydrochloric acid on di-imido-oxalic acid (A. **288**, 289). *Phenylimido-oxalic Methyl Ether*, $CO_2CH_3.C(=N.C_6H_5)OCH_3$.

Di-imido-oxalic Ether, $C_2H_5O.(NH)C—C(NH).OC_2H_5$, m.p. 25°, b.p. 170°. Its hydrochloride is obtained on conducting HCl into an alcoholic solution of cyanogen (B. **11**, 1418) (comp. p. 281).

Oxalamidine, $NH_2(NH)C—C(NH)NH_2$, results from the action of alcoholic ammonia on the hydrochloride of oximido-ether (B. **16**, 1655).

Carbohydrazidine, Oxalodi-imide Dihydrazide,

$$\begin{matrix}HN{:}C.NHNH_2\\ |\\ NH{:}C.NHNH_2\end{matrix}$$

, forms white, flat needles, which assume a reddish-brown colour on heating and do not melt at 250°. It results from the union of cyanogen with hydrazine. *Dibenzal Carbohydrazidine*, m.p. 218° (J. pr. Ch. [2] **50**, 253).

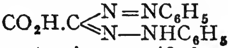
Oxalodihydroxamic Acid, $[C:(NOH)OH]_2$, m.p. 165°, results from oxalic ester and hydroxylamine (B. **27**, 709, 1105).

Oxalodiamidoxime, $[C(N.OH)NH_2]_2$, m.p. 196°, with decomposition. It is formed when NH_2OH acts (1) on cyanogen (B. **22**, 1931), (2) on cyananiline (B. **24**, 801), (3) on hydrorubeanic acid (B. **22**, 2306); *dibenzoyl derivative*, m.p. 222° (B. **27**, R. 736).

Chloroximido-acetic Ester, Ethoxalo-oxime Chloride, $CO_2C_2H_5.C(:NOH)Cl$, m.p. 80°, is obtained from chloracetoacetic ester by means of fuming nitric acid; and when concentrated hydrochloric acid acts on nitrolacetic ester (B. **28**, 1217; **39**, 784). Similarly, chloracetoacetic ester and diazobenzene chloride yield *chlorophenylhydrazido-acetic ester, oxalic ester, phenylhydrazido-chloride*, $CO_2R.C(:NNHC_6H_5)Cl$ (C. 1902, II. 187).

Nitrolacetic Ester, Ethoxalonitrolic Acid, $CO_2C_2H_5.C(:NOH).NO_2$, m.p. 69°, is prepared from isonitroso-acetoacetic ester and nitric acid of sp.gr. 1·2 (B. **28**, 1217).

Formazyl Carboxylic Acid,



$$CO_2H.C\Big\langle\begin{matrix}N=NC_6H_5\\ N—NHC_6H_5\end{matrix}$$

, m.p. 162°, when rapidly heated, is produced when its ester is saponified. The ester results from the action of diazobenzene chloride (1) on the hydrazone of mesoxalic ester, (2) on sodium malonic ester, and (3) on acetoacetic ester, whilst oxalic acid breaks down into formic acid and CO_2, formazyl carboxylic acid decomposes into *formazyl hydride* (p. 244) and CO_2 (B. **25**, 3175, 3201).

Ureïdes of Oxalic Acid, Parabanic acid, and *Oxaluric acid* will be considered together with the derivatives of uric acid (*q.v.*).

THE MALONIC ACID GROUP

Malonic Acid [Propane Diacid], $CH_2(CO_2H)_2$, m.p. 132°, occurs as its calcium salt in sugar-beets. (1) The acid was discovered in 1858, by *Dessaignes,* on oxidizing malic acid, $CO_2H.CH(OH).CH_2CO_2H$, with potassium bichromate (hence the name, from *malum,* apple), and quercitol with potassium permanganate (B. **29**, 1764). It is also produced (2) in the oxidation of hydracrylic acid, and (3) of *propylene* and *allylene* by means of $KMnO_4$. (4) *Kolbe* and *Hugo Müller* obtained it almost simultaneously (1864) by the conversion of chloracetic acid into cyanacetic acid, the nitrile acid of malonic acid, and then saponifying the latter with potassium hydroxide. (5) By the decomposition of barbituric acid or its malonyl urea (*q.v.*). (6) Malonic ester and CO are formed in the distillation of oxalacetic ester (*q.v.*) under the ordinary pressure (B. **27**, 795).

Preparation.—One hundred grams of chloracetic acid, dissolved in 200 grams of water, are neutralized with sodium carbonate (110 grams), and to this 75 grams of pure, powdered potassium cyanide are added, and the whole carefully heated, after solution, upon a water-bath. The cyanide produced is hydrolyzed either by concentrated hydrochloric acid or potassium hydroxide (B. **13**, 1358; A. **204**, 225; C. 1897, I. 282). To obtain the malonic ester directly, the cyanide solution is evaporated, the residue covered with absolute alcohol, and HCl gas led into it (A. **218**, 131), or it is treated with sulphuric acid and alcohol (C. 1897, I. 282).

Properties.—Malonic acid crystallizes in triclinic plates. It is easily soluble in water and alcohol. Above its melting point it decomposes into acetic acid and carbon dioxide. Bromine in aqueous solution converts it into tribromacetic acid and CO_2, whilst iodic acid changes it to di- and tri-iodoacetic acid (p. 489) and CO_2.

Salts.—Barium salt, $(C_3H_2O_4)Ba+2H_2O$: *calcium salt,* $C_3H_2O_4Ca+2H_2O$, dissolves with difficulty in cold water: *silver salt,* $C_3H_2O_4Ag_2$, is a white, crystalline compound.

Ester. *Malonic Mono-ethyl Ester,* b.p.$_{21}$ 147°, is decomposed at higher temperatures into CO_2, acetic ester, acetic acid, and diethyl malonate: *potassium salt* is prepared from the neutral ester and one molecule of alcoholic potassium hydroxide. Electrolysis of this produces succinic ethylene ester (pp. 478, 492) (comp. C. 1900, II. 171; 1905, II. 30, where also are found ester-acids of alkyl malonic acid).

The *neutral malonic esters* are made by treating potassium cyanacetate or malonic acid with alcohols and hydrochloric acid. These compounds are of the first importance in the synthesis of the polycarboxylic acids, because of the replaceability of the hydrogen atoms of the CH_2-group by sodium.

History.—This property was first observed in 1874 by *van't Hoff, Sr.* (B. **7**, 1383), and the possibility of obtaining the malonic acid homologues, by means of it, was indicated. The comprehensive, exhaustive experiments begun in

1879 by *Conrad* first demonstrated that malonic esters were almost as valuable as the acetoacetic esters in carrying out certain synthetic reactions (pp. 412, 415) (A. **204**, 121).

The *methyl ester*, $CH_2(CO_2CH_3)_2$, b.p. 181°; *ethyl ester*, b.p. 198°; D_{18} 1·068. By the action of sodium ethoxide on it the Na-compounds, $CHNa(CO_2C_2H_5)_2$ (p. 490) and $CNa_2(CO_2C_2H_5)_2$ (?), result. *The malonic esters possess the characteristics of weak acids* (B. **17**, 2783; **24**, 2889; **32**, 1876; **36**, 268). *Aluminium Malonic Ester*, $Al[CH(CO_2C_2H_5)]_3$, m.p. 95°, is formed by the action of aluminium amalgam on malonic ester (C. 1900, I. 12).

Reactions of Malonic Ester and its Salts.—Iodine converts both sodium malonic esters into ethane and ethylene tetracarboxylic esters (*q.v.*). Sodium malonic ester, when electrolyzed, yields ethane tetracarboxylic ester (B. **28**, R. 450). Alkyl halides convert the sodium malonic esters into esters of malonic acid homologues (B. **28**, 2616). When sodium acts on malonic ester at 70–90°, alcohol is given off, and there is formed the di-sodium compound of *acetone tricarboxylic ester*. This substance acted on by sodium malonic ester at 145°, loses two molecules of alcohol, whereby tri-sodium *phloroglucinol carboxylic ester* is formed (Vol. II.) (B. **32**, 1272):

$$CO_2C_2H_5CHNa.CNa(CO_2C_2H_5)_2+CHNa(CO_2C_2H_5)_2 \\ =C_6O_3Na_3(CO_2C_2H_5)_3+2C_2H_5OH.$$

Malonic ester condenses with aldehydes under the influence of acetic anhydride, hydrochloric acid, sodium ethoxide, or small quantities of ammonia diethylamine and piperidine. In the last case an intermediate product is formed —alkylidene piperidine, which is converted by malonic ester into alkylidene bismalonic ester (B. **31**, 2585).

The free malonic acid also condenses with aldehydes and with some ketones, when heated with acetic acid, acetic anhydride, or pyridine; water and CO_2 are split off and unsaturated carboxylic acids are formed (pp. 290, 305).

αβ-olefine aldehydes, αβ-olefine ketones, and αβ-olefine carboxylic esters unite with sodium malonic ester, a synthesis in which the $NaC(CO_2R)_2$ residue joins with the β-carbon atom, and the H-atom with the α-carbon atom. The aldehyde groups of the olefine aldehydes under these conditions unite also with two molecules of malonic ester (comp. A. **360**, 323).

Cyanogen combines with malonic ester in presence of a little sodium ethoxide to form *cyanimido-di-isosuccinic ester*, $NC.C(NH)CH(CO_2C_2H_5)_2$, and *di-imido-oxalyl dimalonic ester*, $(C_2H_5OCO)_2CHC(NH).C(NH)CH(CO_2C_2H_5)_2$.

Diazobenzene chloride and malonic ester yield mesoxalic ester phenylhydrazone (*q.v.*).

Malonic Anhydride, $CH_2<\substack{CO\\CO}>O$, is not known (comp. p. 476).

Carbon Suboxide, *Dioxoallene, Carbon Dicarbonyl*, C_3O_2, m.p. −108°, b.p. +7°, $D^0_0=1·1137$, is produced when malonic ester, or, better, malonic acid, is heated with P_2O_5 (*O. Diels*, B. **41**, 82). It may be looked on as being a *double malonic anhydride.* In behaviour it resembles most nearly the ketenes (pp. 474, 475), and is therefore to be looked on as carbon dicarbonyl or dioxoallene: $CO=C=CO$; it may also be considered as being *β-hydroxypropiolic lactone*, $C\substack{\equiv C-\\ -CO}>O$ (B. **41**, 925). Carbon suboxide polymerizes at ordinary temperatures to a dark-red solid mass. Water regenerates malonic acid; ammonia and aniline produce malonamide and maloanilide. Hydrochloric acid forms malonyl chloride; bromine produces dibromomalonyl bromide which reforms carbon suboxide by the action of zinc in ether (B. **41**, 906):

$$CH_2(COOH)_2 \underset{+2H_2O}{\overset{-2H_2O}{\rightleftarrows}} CO=C=CO;\ CO=C=CO \underset{2Zn}{\overset{4Br}{\rightleftarrows}} BrCOCBr_2COBr.$$

Chlorides of Malonic Acid.

Malonyl Chloride Monoethyl Ester, $CO_2C_2H_5.CH_2COCl$, b.p.$_{13}$ 69°, is prepared from ethyl potassium malonate and PCl_5; or malonic ester and $SOCl_2$ (B. **25**, 1504; C. 1905, II. 30; also for *homologous* chloride esters).

Malonyl Chloride, $CH_2(COCl)_2$, b.p.$_{27}$ 58°, is formed by the action of $SOCl_2$

on malonic acid, together with the *monochloride*, $HOCOCH_2COCl$, m.p. 65°, with decomposition (B. **41**, 2208).

Malonamide Monoethyl Ester, $CO_2C_2H_5.CH_2CONH_4$, m.p. 50°, is formed when malonic ester imido-ether hydrochloride (see below) is heated; also from malonyl chloride mono-ester and ammonia (B. **28**, 479; C. 1905, II. 30).

Malonamide, $CH_2(CONH_2)_2$, m.p. 170°. *Malonic Hydrazide*, $CH_2(CONH.NH_2)_2$, m.p. 154°, reacts with aldehydes and ketones with loss of water (B. **39**, 3372; **41**, 641).

Nitriles of Malonic Acid: *Cynacetic Acid, Nitrilomalonic Acid, half nitrile of malonic acid*, $CN.CH_2.CO_2H$ (p. 487), m.p. 70° (B. **27**, R. 262), dissolves very readily in water, and at about 165° breaks down into CO_2 and acetonitrile (p. 280). *Cyanacetic Ethyl Ester*, $CN.CH_2.CO_2C_2H_5$, b.p. 207° (for preparation, see C. 1905, I. 150), forms sodium derivatives like malonic ester (C. 1900, II. 38), by means of which the hydrogen of the CH_2-groups can be replaced by alkyls (B. **20**, R. 477) and acid radicals (B. **21**, R. 353). *Cyanacetamide*, $CN.CH_2.CONH_2$, is prepared from the ester and ammonia, m.p. 118°. *Cyanacetyl Hydrazide*, $CNCH_2CO.NHNH_2$, m.p. 114° (J. pr. Ch. [2] **51**, 186).

Cyanacetic ester unites with alcohol and hydrochloric acid to form *malonic ester imido-ether hydrochloride*, $C_2H_5OCO.CH_2C(:NH.HCl)OC_2H_5$, which, on digestion with alcohol, yields the *half ortho-ester of acid malonic ester* (comp. Ortho-ester, p. 284). The latter loses alcohol and passes into the *acetal of carbomethane carboxylic ester*, called *Diethoxyacrylic Ester*, $(C_2H_5O)_2C{=}CH.CO_2C_2H_5$, b.p.$_{12}$ 128°. This substance, when shaken with water, is converted into malonic ester; bromine produces an oily dibromide, and with an increased quantity, dibromo malonic ester (B. **40**, 3358).

Malononitrile, *Methylene Cyanide*, $CH_2(CN)_2$, m.p. 30°, b.p. 218°, is obtained by distilling cyanacetamide with P_2O_5 (C. 1897, I. 32). It is soluble in water. Ammoniacal silver nitrate precipitates $CAg_2(CN_2)$ from the aqueous solution (B. **19**, R. 485). Hydrazine and malononitrile yield *Diamidopyrazole*, $C_3N_2H_2(NH_2)_2$ (B. **27**, 690) (see also cyanoform). *Methenylamidoxime Acetic Acid*, $NH_2(HON):C.CH_2CO_2H$, m.p. 144° (B. **27**, R. 261; A. **321**, 357). *Nitrilomalonimidoxime, Cyanethenylamidoxime*, $CN.CH_2C(:NOH)NH_2$, m.p. 124–127°. *Malondihydroxamic Acid*, $CH_2[C(:NOH)OH]_2$, m.p. 154° (B. **27**, 803). *Malondiamidoxime*, $CH_2.[C(:N.OH)NH_2]_2$, m.p. 163–167° (B. **29**, 1168).

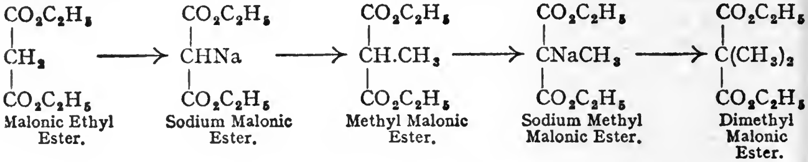
The *ureïdes of malonic acid* and *cyanacetic acid* will be treated later in connection with uric acid (*q.v.*).

Halogen-substituted Malonic Acids are formed by the action of chlorine or sulphuryl chloride, bromine or iodine and iodic acid on malonic acid or its esters. Such malonic and alkyl malonic acids (see below) easily part with CO_2 and form α-halogen fatty acids, some of which are conveniently prepared in this way (B. **35**, 1374 1813; **39**, 351). *Monochloromalonic Acid*, $CHCl(COOH)_2$; *ethyl ester*, b.p. 222°. *Monobromomalonic Acid*, $CHBr(COOH)_2$, b.p. 113°, with decomposition; *methyl ester*, b.p. 215–225°. *Dichloromalonic Acid*, $CCl_2(COOH)_2$; *ethyl ester*, b.p. 231–234°; *amide*, m.p. 203°. *Dibromomalonic Acid*, $CBr_2(COOH)_2$, m.p. 147°, with decomposition; *dimethyl ester*, m.p. 64°. *Dibromomalonic Nitrile*, m.p. 65° (C. 1897, I. 32). *Dibromomalonyl Bromide*, b.p.$_{13}$ 92° (see p. 488, Carbon Suboxide). *Dibromomalonamide*, m.p. 200.° *Di-iodomalonic Acid*, $CI_2(COOH)_2$, is prepared from malonic acid, iodine, and iodic acid in formic acid. It is extremely unstable; *methyl ester*, m.p. 80°, can be obtained from dibromomalonic ester and KI.

The mono- and di-halogen malonic acids serve as a connecting link between malonic acid and *tartronic* and *mesoxalic acids*. *Monobromo-* and *mono-iodocyanacetic Esters*, $CN.CHXCO_2R$, are obtained from sodium cyanacetic ester with bromine or iodine in the cold. At higher temperatures dicyanosuccinic ester and tricyano-trimethylene tricarboxylic esters are formed (C. 1900, II. 38, 1202).

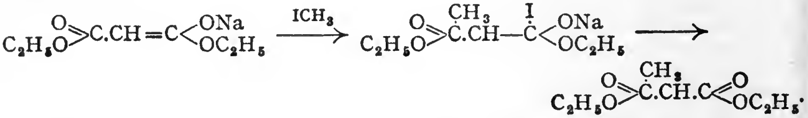
Monothio-bis-malonic ester, $S[CH(CO_2R)_2]_2$, *Dithio-bis-malonic Ester*, $S_2[CH(CO_2R)_2]_2$, and *tri-thio-bis-malonic ester*, $S_3[CH(CO_2R)_2]_2$, are formed from malonic ester and S_2Cl_2 (B. **36**, 3721).

Alkyl Malonic Acids.—The general methods suitable for the preparation of alkyl malonic acids are (1) reaction 5*a* (p. 477), conversion of α-halogen fatty acids into α-cyano-fatty acids—the half nitriles of the malonic acid homologues; and (2) reaction 6 (p. 478), the replacement of the hydrogen atoms of the CH_2 group in the malonic esters by alkyls. First, with the aid of sodium ethoxide, or sodium in ether (J. pr. Ch. **72**, 537), monosodium malonic esters are made, which alkyl iodides convert into mono-alkyl malonic esters. These are further able to yield monosodium alkyl malonic esters, which alkylogens change to dialkyl malonic esters—*e.g.*:



$$\begin{array}{c}CO_2C_2H_5\\|\\CH_2\\|\\CO_2C_2H_5\end{array}\longrightarrow\begin{array}{c}CO_2C_2H_5\\|\\CHNa\\|\\CO_2C_2H_5\end{array}\longrightarrow\begin{array}{c}CO_2C_2H_5\\|\\CH.CH_3\\|\\CO_2C_2H_5\end{array}\longrightarrow\begin{array}{c}CO_2C_2H_5\\|\\CNaCH_3\\|\\CO_2C_2H_5\end{array}\longrightarrow\begin{array}{c}CO_2C_2H_5\\|\\C(CH_3)_2\\|\\CO_2C_2H_5\end{array}$$

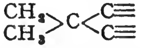
It has previously been mentioned under acetoacetic ester (p. 412) that the reaction consists in the addition of sodium ethoxide to the carboxethyl group, with the splitting-off of alcohol and the production of a double union, to which the alkylogen attached itself, followed by the elimination of a sodium halide (A. **280**, 264):



$$\begin{array}{l}O\\C_2H_5O\end{array}\!\!>C.CH=C<\begin{array}{l}ONa\\OC_2H_5\end{array}\xrightarrow{ICH_3}\begin{array}{l}O\\C_2H_5O\end{array}\!\!>\overset{CH_3}{C.CH}-\overset{I}{C}<\begin{array}{l}ONa\\OC_2H_5\end{array}\longrightarrow\begin{array}{l}O\\C_2H_5O\end{array}\!\!>\overset{CH_3}{C.CH}.C<\begin{array}{l}O\\OC_2H_5\end{array}.$$

Alkyl malonic esters are also formed when alkyl oxalacetic esters lose CO_2 (B. **31**, 551).

Some of these dialkyl malonic acids are formed when complex carbon derivatives are oxidized—*e.g.* dimethyl malonic acid results from the oxidation of unsym.-dimethyl ethylene succinic acid, mesitonic acid, camphor, etc. The production of dimethyl malonic acid in this manner proves the presence, in these bodies, of the atomic grouping—



$$\begin{array}{l}CH_3\\CH_3\end{array}\!\!>C<\begin{array}{l}C\equiv\\C\equiv\end{array}$$

All mono- and dialkyl malonic acids, when exposed to heat, lose CO_2 *and pass into mono-* (B. **27**, 1177) *and dialkyl acetic acids* (p. 476).

See Z. phys. Ch. **8**, 452, for the affinities of the alkyl malonic acids. Consult B. **29**, 1864; J. pr. Ch. [2] **72**, 537, upon the velocity of hydrolysis of the alkyl malonic esters.

Isosuccinic Acid, *Ethylidene Succinic Acid, Methyl Malonic Acid* [Methyl-propane Di-acid], $CH_3CH(CO_2H)_2$, m.p. 130° with decomposition, is isomeric with ordinary succinic acid or ethylene succinic acid (p. 491), and is obtained (1) from α-chloro- and α-bromo-propionic acids through the cyanide (B. **13**, 209), and (2) from sodium malonic ester and methyl iodide (A. **347**, 93).

When ethylidene bromide, $CH_3.CHBr_2$, is heated with potassium cyanide and alkalis, the expected ethylidene succinic acid is not formed, but by molecular rearrangement, ordinary ethylene succinic acid results.

The acid is more soluble than ordinary succinic acid in water. If heated above 130°, it breaks up into carbon dioxide and propionic acid (p. 258); *ethyl ester*, b.p. 196°; *methyl ester*, b.p. 179°; *diamide*, m.p. 216°.

For the rules of formation of the *diamides* of *homologous allkyl* and *di-alkylmalonic acids*, see B. **39**, 1596; C. 1905, II. 725; 1906, I. 1235, etc.

a-Cyanopropionic Ester, $CH_3CH(CN)CO_2C_2H_5$, b.p. 197–198°.

Bromisosuccinic Acid, $CH_3CBr(CO_2H)_2$, m.p. 118–119° (B. **23**, R. 114).

Methyl Bromomalonic Ester, b.p.$_{25}$ 115–118° (B. **26**, 2356).

Ethyl Malonic Acid, $C_2H_5.CH(CO_2H)_2$, m.p. 111·5°. The *ethyl ester*, b.p. 200°; *amide*, m.p. 216°; *Ethyl Bromomalonic Ester*, b.p. 125° (B. **26**, 2357).

Dimethyl Malonic Acid, $(CH_3)_2C(CO_2H)_2$, m.p. 185° with decomposition (A. **247**, 105); *ethyl ester*, b.p. 195°; *amide*, m.p. 261°; *nitrile*, m.p. 32°, b.p.$_{22}$ 64°; *dichloride*, m.p. 165°. The latter, with aqueous pyridine, yields a polymeric anhydride, $[(CH_3)_2C(CO)_2O]_x$ (A. **359**, 169), which can also be formed by heating the *monochloride*, $HOCOC(CH_3)_2COCl$, m.p. 65° with decomposition; and also by prolonged heating of *dimethyl ketene* (p. 475) (B. **41**, 2212).

In the case of the subjoined alkyl malonic acids, the boiling points of the ethyl esters (inclosed in parentheses) are given, together with the melting points of the acids.

Propyl Malonic Acid, $CH_3CH_2CHCH(CO_2H)_2$, m.p. 96° (219–222°).

Isopropyl Malonic Acid $(CH_3)_2CH.CH(CO_2H)_2$, m.p. 87° (213–214°).

Methyl Ethyl Malonic Acid, $CH_3(C_2H_5)C(CO_2H)_2$, m.p. 118° (207–208°).

n.-Butyl Malonic Acid, $CH_3(CH_2)_3.CH(CO_2H)_2$, m.p. 101·5°. *Isobutyl Malonic Acid*, m.p. 107° (225°). sec.-*Butyl Malonic Acid*, $CH_3(C_2H_5)CH.CH(CO_2H)_2$, m.p. 76° (233–234°). *Propyl Methyl Malonic Acid*, $CH_3(CH_3.CH_2CH_2)C(CO_2H)_2$, m.p. 107° (220–223°). *Isopropyl Methyl Malonic Acid*, m.p. 124° (221°). *Diethyl Malonic Acid*, m.p. 121° (A. **292**, 134); *dimethyl ester*, b.p. 205°; *chloride*, b.p. 197°, yields a polymeric *anhydride*, $[(C_2H_5)_2C(CO)_2O]_{12}$, when treated with pyridine and soda solution. Boiling in benzene partially de-polymerizes it, whilst when heated alone it is decomposed into *diethyl ketene* (p. 475) and CO_2 (A. **359**, 159; B. **41**, 2216); *amide*, m.p. 224° (B. **35**, 854; A. **359**, 174; C. 1906, I. 1237). *Di-ethyl Malonic Acid Nitrile*, m.p. 44°, b.p.$_{24}$ 92°. *Veronal* is a ureïde of this acid (see Barbituric acid).

Pentyl Malonic Acid, $CH_3[CH_2]_4CH(CO_2H)_2$, m.p. 82°. *Dipropyl Malonic Acid*, $(CH_3CH_2CH_2)_2C(CO_2H)_2$, m.p. 158°. *Cetyl Malonic Acid*, $CH_3[CH_2]_{15}CH(CO_2H)_2$, m.p. 122° (A. **204**, 130; **206**, 357; B. **24**, 2781).

For *alkyl* and *di-alkyl cyanacetic esters* and *amides*, see also A. **340**, 310.

THE ETHYLENE SUCCINIC ACID GROUP

Ethylene succinic acid and its alkyl derivatives, as mentioned in the introduction, are characterized by the fact that when heated they break down into anhydrides and water. The anhydride formation takes place more readily in the alkyl succinic acids, the more hydrogen atoms of the ethylene residue of the succinic acid are replaced by alkyl radicals.

The alkyl succinic acids form anhydrides more readily with acetyl chloride, and are more volatile in aqueous vapour than their isomeric alkyl n-glutaric acids (A. **285**, 212). The sym.-dialkyl succinic acids show remarkable isomeric phenomena, which will be more fully discussed under the symmetrical dimethyl succinic acids (p. 493).

The following serve to characterize a succinic acid: (1) the anhydride; (2) the anilic acid, which appears in the chloroform, ethereal, or benzene solution of the anhydride; (3) the anil, produced by heating the anilic acid, or by the action of phosphorus pentachloride or acetyl chloride on it (A. **261**, 145; **285**, 226; **309**, 316).

The anhydrides of the succinic acids unite with alcohols to form acid esters, which are also formed by partial exterification of the acids, and by partial hydrolysis of the neutral esters. The production of unsymmetrically substituted succinic acids is effected mainly by means of the two first methods; the last is employed when preparing certain isomeric acid esters (comp. C. 1904, I. 1484; A. **354**, 117).

Ordinary Succinic Acid, *Ethylene Dicarboxylic Acid*, $CO_2H.CH_2$-$CH_2.CO_2H$, m.p. 185°, b.p. 235°, with decomposition into water and succinic anhydride, is isomeric with methyl malonic acid, or isosuccinic acid (p. 490). It occurs in amber, in some varieties of lignite, in resins, in turpentine oils, and in animal fluids. It is formed in the oxidation of fats with nitric acid, in the fermentation of calcium malate or ammonium tartrate (A. **14**, 214), and in the alcoholic fermentation of sugar (p. 115).

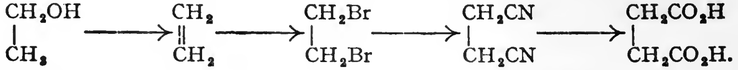
In the general methods of formation (p. 476) ethylene succinic acid has been in part the example chosen. It is produced (1) by the oxidation of γ-butyrolactone and of succinic dialdehyde.

(2) By the reduction of fumaric and maleïc acids with nascent hydrogen.

(3) By reducing (*a*) malic acid (hydroxysuccinic acid) and tartaric acid (dihydroxysuccinic acid) with hydriodic acid, or by the fermentation of these bodies; (*b*) by the action of sodium amalgam on halogen succinic acids.

It is a nucleus-synthetic product obtained in small quantities (4) by the action of finely divided silver on bromacetic acid.

(5*a*) By converting β-iodopropionic acid (p. 289) into the cyanide and decomposing the latter with alkalis or acids. (5*b*) *M. Simpson*, in 1861, was the first to prepare it synthetically from ethylene, by converting the latter into the cyanide. Succinic acid is formed by boiling its dinitrile with potassium hydroxide or mineral acids:



$$\begin{array}{l}CH_2OH\\ |\\ CH_3\end{array} \longrightarrow \begin{array}{l}CH_2\\ \|\\ CH_2\end{array} \longrightarrow \begin{array}{l}CH_2Br\\ |\\ CH_2Br\end{array} \longrightarrow \begin{array}{l}CH_2CN\\ |\\ CH_2CN\end{array} \longrightarrow \begin{array}{l}CH_2CO_2H\\ |\\ CH_2CO_2H.\end{array}$$

Ethylidene chloride and potassium cyanide also yield ethylene cyanide (p. 499).

(6) By the electrolysis of potassium ethyl malonic ester (p. 487) the ester is produced.

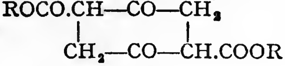
(7) By the decomposition of acetosuccinic esters, (8) of ethane tricarboxylic acid, (9) of sym.-ethane tetracarboxylic acid.

Succinic acid crystallizes in monoclinic prisms or plates, and has a faintly acid, disagreeable taste. At the ordinary temperature it dissolves in 20 parts of water.

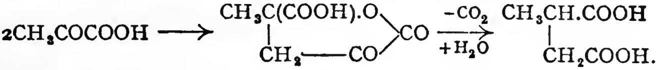
Uranium salts decompose aqueous succinic acid in sunlight into propionic acid and CO_2. The electric current decomposes the potassium salt into ethylene, carbon dioxide, and potassium (p. 81).

Paraconic Acids, *γ-lactone carboxylic acids*, are formed when sodium succinate is heated with aldehydes and acetic anhydride (*Fittig*, A. **255**, 1). When succinic acid, zinc chloride, sodium acetate, and acetic anhydride are heated to 200°, small quantities of $\alpha\alpha'$-dimethyl β-acetyl pyrrole (B. **27**, R. 405) are produced. When calcium succinate is distilled, *p*-diketo-hexamethylene (Vol. II.) is produced in small quantities (B. **28**, 738).

Succinates: calcium salt, $C_4H_4O_4Ca+3H_2O$, separates from a cold solution, but when it is deposited from a hot liquid it contains only $1H_2O$. When ammonium succinate is added to a solution containing a ferric salt, all the iron is precipitated as reddish-brown basic ferric succinate (separation of iron from aluminium).

Esters. Potassium Ethyl Succinate when electrolyzed yields *adipic ester* (p. 505) *Monomethyl Succinate*, m.p. 58°, is prepared from the anhydride and alcohol (C. 1904, I. 1484). *Dimethyl Succinate*, $CO_2CH_3.CH_2.CH_2CO_2CH_3$, m.p. 19°, $b.p._{10}$ 80°. *Diethyl Succinate*, b.p. 216°. Sodium converts it into succinyl succinic ester,  $\begin{array}{l}ROCO.CH\text{—}CO\text{—}CH_2\\ \quad\ \ |\qquad\qquad\ \ |\\ CH_2\text{—}CO\text{—}CH.COOR\end{array}$ (*q.v.*). *Ethylene Succinate* (A. **280**, 177).

Mono-alkyl Succinic Acids. Pyrotartaric Acid, *Methyl Succinic Acid*,  $\begin{array}{l}CH_3.CH.CO_2H\\ |\\ CH_2.CO_2H\end{array}$, m.p. 112°, was first obtained in (1) the dry distillation of tartaric acid. It is produced (2) from pyroracemic acid or its condensation product, keto-valerolactone carboxylic acid, when heated with hydrochloric acid (A. **317**, 22):

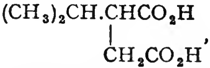


$$2CH_3COCOOH \longrightarrow \begin{array}{l}CH_3C(COOH).O\\ |\\ CH_2\text{——}CO\end{array}\!\!>CO \xrightarrow[+H_2O]{-CO_2} \begin{array}{l}CH_3CH.COOH\\ |\\ CH_2COOH.\end{array}$$

The remaining methods of formation correspond with those for the production of succinic acid; (3) by the reduction of ita-, citra-, and mesa-conic acids (p. 515); (4) from β-bromobutyric acid and propylene bromide by means of potassium cyanide; (5) from α- and β-methyl acetosuccinic esters; and (6) from α- and β-methyl ethane tricarboxylic acids. The acid dissolves readily in water, alcohol, and ether. When quickly heated above 200° it decomposes into water and the anhydride. If, however, it be exposed for some time to a temperature of 200–210°, it splits into CO_2 and butyric acid. It undergoes the same decomposition when in aqueous solution, if acted on by sunlight in presence of uranium salts (B. **24**, R. 310). Resolution into its *optically active* components is effected by strychnine (B. **29**, 1254). *Dextro-rotatory* pyrotartaric acid is also formed when menthone is oxidized.

Potassium Salt, $C_5H_6O_4K_2$; *calcium salt*, $C_5H_6P_4Ca+2H_2O$, dissolves with difficulty in water; *methyl ester*, $b.p._{20}$ 153°; *ethyl ester*, $b.p._{23}$ 160°; *dimethyl ester*, b.p. 197°; *diethyl ester*, b.p. 218° (B. **26**, 337; C. 1900, I. 169; 1904, I. 1484).

Ethyl Succinic Acid, m.p. 98°. n-*Propyl Succinic Acid*, (A. **292**, 137). *Isobutyl Succinic Acid*, m.p. 107° (A. **304**, 270).

Pimelic Acid, *Isopropyl Succinic Acid*,  $\begin{array}{l}(CH_3)_2CH.CHCO_2H\\ \qquad\qquad\ |\\ \qquad\quad CH_2CO_2H\end{array}$, m.p. 115°, was first prepared by fusing camphoric acid and tanacetogen dicarboxylic acid (B. **25**, 3350) with potassium hydroxide. It may be synthetically obtained from acetoacetic or malonic esters (A. **292**, 137; **298**, 150), as well as from the products of the action of potassium cyanide on isocaprolactone at 280° (C. 1897, I. 408).

sym.-Dialkyl Succinic Acids, $CO_2H.CHR'\text{—}CHR'.CO_2H$.

Symmetrical dimethyl succinic acid exists, like the other symmetrical disubstituted succinic acids—*e.g.* dibromosuccinic acid (p. 500), diethyl-, methyl-ethyl-, di-isopropyl-, and diphenyl-succinic acids—in two different forms, having the same structural formulæ.

Dihydroxysuccinic acid or tartaric acid occurs in two active and two inactive forms (one can be resolved and the other cannot), which are satisfactorily explained by *van 't Hoff's* theory of *asymmetric* carbon atoms (p. 30). The pairs of isomeric dialkyl succinic acids, also containing asymmetric carbon atoms, manifest certain analogies with *paratartaric acid* (racemic acid), and *anti-* or *meso-tartaric acid.* Hence it is assumed that their isomerism is due to the same cause. The higher melting, more difficultly soluble modification is called the *para*-form, whilst the *meso-* or *anti*-form is more readily soluble, and melts lower (*Bischoff*, B. **20**, 2990; **21**, 2106). However, this assumption is doubtful, inasmuch as not one of the constantly inactive dialkyl succinic acids has ever been converted into an active variety (B. **22**, 1812). *Bischoff* has set forth a theory of *dynamical isomerism* (B. **24**, 1074, 1085) in which he presents views in regard to the equilibrium positions of the atoms and radicals, joined to the two asymmetric carbon atoms, in the symmetrical dialkylic succinic acids.

Isomeric pairs of the dialkyl succinic acids are formed (according to method 2, p. 477) by the reduction of dialkyl maleïc anhydrides, such as pyrocinchonic anhydride (p. 518), by means of HI or sodium amalgam (B. **20**, 2737; **23**, 644); from α-monohalogen fatty acids by finely divided silver (method of formation 4) (B. **22**, 60); from α-monohalogen fatty acids by the action of potassium cyanide (B. **21**, 3160); from aceto-dialkyl-succinic esters by elimination of the acetyl group (method 8); from sym.-dialkyl ethane polycarboxylic acids by heating them with hydrochloric (method 9) (comp. p. 492).

In all these reactions both dialkyl succinic acids are formed together, and may be separated by crystallization from water.

sym.-Dimethyl Succinic Acids, $CO_2H.CH(CH_3)—CH(CH_3)CO_2H$.

The *para*-acid, m.p. 192–194°, is soluble in 96 parts of water at 14°. It forms needles and prisms, which lose some water upon melting. If the acid be heated for some time to 180–200°, it yields a mixture of the *anhydrides* of the *para-* and *anti*-acid, $C_6H_8O_3$, m.p. 38° and 87°. With water each reverts to its corresponding acid. When acetyl chloride acts on the *para*-acid, its *anhydride*, m.p. 38°, is the only product. This crystallizes from ether in rhombic plates, and unites with water to form the pure *para*-acid (B. **20**, 2741; **21**, 3171; **22**, 389; **23**, 641; **29**, R. 420).

If the *para*-acid be heated to 130° with bromine, it yields pyrocinchonic anhydride, $C_6H_6O_3$ (p. 518). Both acids, when digested with bromine and phosphorus, yield the same bromo-dimethyl-succinic acid, $C_6H_9BrO_4$, m.p. 91°. Zinc and hydrochloric acid change it to the *anti*-acid (B. **22**, 66). The *ethyl ester* of the *para*-acid (from the silver salt) b.p. 219°; *methyl ester*, b.p. 199°.

The *meso-* or *anti*-acid, m.p. 120–123° (after repeated crystallizations from water) (analogous to antitartaric acid and maleïc acid) dissolves in 33 parts of water at 14°. It crystallizes in shining prisms. It yields its *anhydride*, $C_6H_8O_3$, m.p. 87°, when heated to 200°. It regenerates the acid with water. If the *anti*-acid be heated with hydrochloric acid to 190°, it becomes the *para*-acid. The *methyl ester*, b.p. 200°; *ethyl ester*, b.p. 222°. When the *anti*-acid is esterified with HCl, it yields a mixture of the esters of the *anti-* and *para*-acid (B. **22**, 389, 646; **23**, 639). The ethyl ester is also obtained when α-iodopropionic ester is shaken with mercury in sunlight (C. 1902, I. 408).

The *monomethyl ester* of the *para-acid*, m.p. 38°, and of the *anti-acid*, m.p. 49°, are obtained by the action of methyl alcohol on the anhydrides (C. 1904, I. 1484).

sym.-Methyl Ethyl Succinic Acids, $CO_2H.CH(CH_3).CH(C_2H_5)CO_2H$. The *para*-acid, m.p. 179°; *anti-* or *meso*-acid, m.p. 101° (A. **298**, 147).

sym.-Methyl Isopropyl Succinic Acids: The *para*-acid, m.p. 174°; *meso*-acid, m.p. 125° (B. **29**, R. 422).

sym.-Diethyl Succinic Acids.—The *para*-acid, m.p. 189–192°; *anti-acid*, m.p. 129° (B. **20**, R. 416; **21**, 2085, 2105; **22**, 67; **23**, 650).

The para- and meso-forms of the sym.-*di*-n.-*propyl succinic acid*, *di-isopropyl succinic acid*, and *propyl isopropyl succinic acid* are prepared by the introduction of propyl or isopropyl groups into propyl or isopropyl cyanosuccinic ester followed by hydrolysis and decomposition of the condensation products. Di-isopropyl succinic acid also results from bromisovaleric ester and silver (A. **292**, 162; C. 1900, I. 846, 1205). Other sym.-dialkyl succinic acids, see C. 1901, I. 167.

Unsymmetrical Succinic Acids.

uns.-*Dimethyl Succinic Acid*, $CO_2H.CH_2.C(CH_3)_2.CO_2H$, m.p. 140°, is synthesized from α-dimethyl ethane tricarboxylic ester by the action of boiling sulphuric acid. The ester is the reaction product of bromisobutyric ester and sodium malonic ester (C. 1898, I. 885). It can also be obtained from dimethyl cyanethane dicarboxylic ester, the product of reaction of sodium cyanacetic acid and α-bromisobutyric ester; from the acid nitrile, the product of the interaction of potassium cyanide and β-chlorisovaleric acid (C. 1899, I. 182); also, from its nitrile (p. 499). The imide (p. 497) is obtained by oxidation of mesitylic acid. Esterification of uns.-dimethyl succinic acid proceeds by first attacking the carboxyl group attached to the CH_2-group, producing uns.-*Dimethyl Succinic α-Mono-ethyl Ester*, $CO_2H.C(CH_3)_2.CH_2CO_2C_2H_5$, m.p. 70°, b.p.$_{14}$ 150°. This substance can also be obtained by the action of alcohol on dimethyl succinic anhydride. Partial hydrolysis of uns.-*Dimethyl Succinic Diethyl Ester*, b.p. 215°, produces the liquid isomer *dimethyl succinic β-mono-ethyl ester* (Private communication of *Anschütz* and *Güttes*). uns.-*Dimethyl Succinic Monomethyl Ester*, m.p. 42° and 51° (C. 1904, I. 1485).

Trimethyl Succinic Acid, $CO_2H.\overset{*}{C}H(CH_3)—C(CH_3)_2.CO_2H$, m.p. 151° (A. **292**, 142), results on hydrolyzing the tricarboxylic ester (B. **24**, 1923) produced in the action of bromisobutyric ester on sodium methyl malonic ester, or sodium α-cyanopropionic ester, as well as in the oxidation of camphoric acid (B. **26**, 2337); and by fusing camphoronic acid with potassium hydroxide (Vol. II.; A. **302**, 51). The formation of trimethyl succinic anhydride from *camphoronic acid* by distillation is rather important in the recognition of the constitution of camphor (B. **26**, 3047). Trimethyl succinic acid is resolved into its *optically active* components by means of the quinine salts (C. 1901, I. 513).

Tetramethyl Succinic Acid, $CO_2H.C(CH_3)_2.C(CH_3)_2CO_2H$, m.p. 190–192, with loss of water, is formed, together with trimethyl glutaric acid (p. 504), when α-bromisobutyric acid (or its ethyl ester) is heated with silver (B. **23**, 297; **26**, 1458); also by electro-synthesis from potassium dimethyl malonic ester, and from azobutyronitrile (p. 397) (A. **292**, 220); *monomethyl ester*, m.p. 63°.

Tetra-ethyl Succinic Acid, m.p. 149° with conversion into anhydride, and *Tetrapropyl Succinic Acid*, m.p. 137°, are obtained by hydrolysis of the respective dialkyl malonic mono-esters (C. 1905, II. 670; 1906, II. 500).

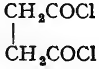
These tetra-alkylated succinic acids pass very readily into their anhydrides.

Chlorides of the Ethylene Succinic Acid Group.

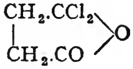
Of the possible chlorides, the *monochloride*, $Cl.CO.CH_2.CH_2.CO_2H$, is only known in the form of its *ethyl ester*, b.p.$_{90}$ 144°, which results from the action of $POCl_3$ (B. **25**, 2748) on sodium succinic ethyl ester.

Succinyl Chloride, m.p. 16°, b.p.$_{25}$ 103°, results from the action of PCl_5 on succinic acid.

Two formulæ have been suggested for this substance, a symmetrical (1), and an unsymmetrical one (2):

(1) 

$$\begin{matrix} CH_2COCl \\ | \\ CH_2COCl \end{matrix}$$

(2) 

$$\left.\begin{matrix} CH_2.CCl_2 \\ | \\ CH_2.CO \end{matrix}\right\rangle O$$

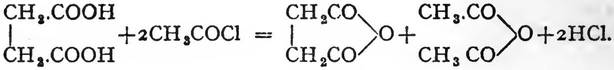
This latter view would make succinyl chloride a dichloro-substitution product of *butyrolactone*, into which it passes on reduction. The behaviour of succinyl chloride towards zinc ethide is in harmony with its lactone formula, for it then yields *γ-diethyl butyrolactone* (p. 374), and in the presence of benzene and aluminium chloride it chiefly affords *γ-diphenyl butyrolactone* (B. **24**, R. 320). A small quantity of *dibenzoyl ethane*, $C_6H_5CO.CH_2CH_2.COC_6H_5$, is produced at the same time. These reactions, whilst supporting the unsymmetrical formula, do not completely exclude the symmetrical representation (comp. B. **30**, 2268).

Pyrotartryl Chloride, $C_5H_6O_2Cl_2$, b.p. 190–195° (B. **16**, 2624). uns.-*Dimethyl Succinyl Chloride*, $C_6H_8O_2.Cl_2$, b.p. 200–202° (A. **242**, 138, 207).

Anhydrides of the Ethylene-Succinic Acid Group.

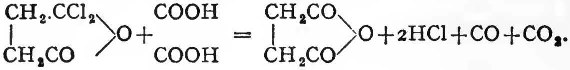
The ready formation of anhydride is characteristic of ethylene succinic acid and its alkyl derivatives. It proceeds the more easily the more the hydrogen atoms of the ethylene group are replaced by alcohol radicals (p. 492).

Formation.—(1) By heating the acids alone. (2) By the action of P_2O_5 (B. **28**, 1289), PCl_5 or $POCl_3$ (A. **242**, 150) on the acids. (3) By treating the acids with the chloride or anhydride of a monobasic fatty acid, *e.g.* acetyl chloride or acetic anhydride (*Anschütz*, A. **226**, 1):

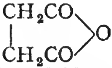


$$\begin{matrix}CH_2.COOH\\|\\CH_2.COOH\end{matrix} + 2CH_3COCl = \begin{matrix}CH_2CO\\|\\CH_2CO\end{matrix}\!\!>O + \begin{matrix}CH_3.CO\\CH_3\,CO\end{matrix}\!\!>O + 2HCl.$$

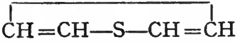
(4) When the chloride of a dicarboxylic acid acts (*a*) on the acid, or (*b*) on anhydrous oxalic acid (A. **226**, 6):



$$\begin{matrix}CH_2.CCl_2\\|\\CH_2CO\end{matrix}\!\!>O + \begin{matrix}COOH\\COOH\end{matrix} = \begin{matrix}CH_2CO\\|\\CH_2CO\end{matrix}\!\!>O + 2HCl + CO + CO_2.$$

Succinic Anhydride,  $\begin{matrix}CH_2CO\\|\\CH_2CO\end{matrix}\!\!>O$, m.p. 120°, b.p. 261°. *Methyl Succinic Anhydride, Pyrotartaric Anhydride,* m.p. 32°, b.p. 247° (A. **336**, 299; C. 1904, I. 1485). *Ethyl Succinic Anhydride,* b.p. 243°. *Isopropyl Succinic Anhydride,* b.p. 250°. *Para-* and *Meso*-sym.-*dimethyl Succinic Anhydride,* m.p. 38° and 87°, respectively (B. **26**, 1460; C. 1899, II. 610). *Meso*-sym.-*methyl Ethyl* and *Meso*-sym.-*diethyl Succinic Anhydrides,* m.p. 244°, b.p. 245°. unsym.-*Dimethyl Succinic Anhydride,* m.p. 29°, b.p. 219°. *Trimethyl Succinic Anhydride,* m.p. 31°, $b.p._{760}$ 231°; $b.p._{12}$ 101°. *Tetramethyl Succinic Anhydride,* m.p. 147°, b.p. 230·5°. *Tetra-ethyl Succinic Anhydride,* m.p. 86°, b.p. 270°. *Tetrapropyl Succinic Anhydride,* m.p. 370°.

Properties and Reactions.—Succinic anhydride has a peculiar, faint, penetrating odour. It can be recrystallized from chloroform. It reverts to succinic acid in moist air, but more rapidly when boiled with water. It yields succinic alkyl ester acids with alcohols. Ammonia and amines change it to succinamic and alkyl succinamic acids. PCl_5 changes it to succinyl chloride. Sodium amalgam reduces it to butyrolactone (B. **29**, 1193); reduction of homologous succinic anhydrides by sodium and alcohol produces γ-lactones and even 1,4-glycols (comp. pp. 310, 373). If the anhydride is boiled for some time it loses CO_2 and changes to the dilactone of *acetone diacetic acid,* $CO(CH_2.CH_2\text{-}CO_2H)_2$ (*q.v.*); P_2S_3 converts succinic acid and sodium succinate into *thiophene,*



$\overline{CH{=}CH{-}S{-}CH{=}CH}$ (*q.v.*). The homologues of succinic anhydride resemble the latter in behaviour.

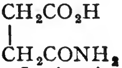
unsym.-Dimethyl succinic anhydride is partially decomposed by Al_2Cl_6 in chloroform into CO, H_2O, and dimethyl acrylic acid, $(CH_3)_2C{:}CHCOOH$ (C. 1902, I. 567).

Peroxides.

Succinyl Peroxide, $(C_4H_4O_4)$, is obtained from succinyl chloride and sodium peroxide. It is a very explosive crystalline powder (B. **29**, 1724). *Succinic Peroxide,* $O_2(COCH_2CH_2COOH)_2$, m.p. 124° with decomposition, is prepared from succinic anhydride and 7·5 per cent. H_2O_2 solution. It explodes when heated, and decomposes in xylene solution into CO_2, a small quantity of *adipic acid* (p. 505), succinic anhydride, and other bodies. Water hydrolyses it into succinic acid and *succinic hydrogen peroxide,* $HOCOCH_2CH_2CO.OOH$, m.p. 107° with decomposition, which decomposes on careful heating into CO_2, H_2O, and acrylic acid (C. 1904, II. 765).

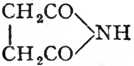
NITROGEN-CONTAINING DERIVATIVES OF THE ETHYLENE SUCCINIC ACID GROUP

Ethylene succinic acid, like oxalic acid, yields an imide, a diamide, a nitrile acid and dinitrile:



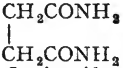
$\begin{matrix}CH_2CO_2H\\|\\CH_2CONH_2\end{matrix}$

Succinamic Acid.



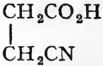
$\begin{matrix}CH_2CO\\|\\CH_2CO\end{matrix}\!\!>NH$

Succinimide,



$\begin{matrix}CH_2CONH_2\\|\\CH_2CONH_2\end{matrix}$

Succinamide.



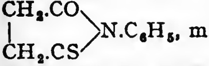
$\begin{matrix}CH_2CO_2H\\|\\CH_2CN\end{matrix}$

β-Cyanopropionic Acid.

$\begin{matrix}CH_2CN\\|\\CH_2CN\end{matrix}$

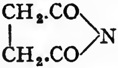
Ethylene Cyanide.

(*a*) **Amido-Acids** (A. **309**, 316).—Most of these have been prepared by decomposing the imides with alkalis or barium hydroxide. They are also formed on adding ammonia, primary aliphatic amines, and aromatic amines (*e.g.* aniline and phenyl-hydrazine) to acid anhydrides. They behave like oxamic acid (p. 483). When heated, or when treated with dehydrating agents, *e.g.* PCl_5 or CH_3COCl, they become converted into imides, which bear the same relation to them that the anhydrides sustain to the dicarboxylic acids. *Succinamic Acid,* $CO_2H.CH_2CH_2.CONH_2$, is obtained from succinimide by the action of barium hydroxide solution. *Succinamic Methyl Ester,* m.p. 90°, is obtained from succinimide and methyl alcohol at 178° (C. 1899, II. 864). *Succinethylamic Acid,* $CO_2H.CH_2CH_2.CONHC_2H_5$ (A. **251**, 319). *Succinanilic Acid,* $CO_2HCH_2CH_2CONHC_6H_5$ (B. **20**, 3214); *methyl ester,* m.p. 98°, is obtained from succinanil (p. 498) and sulphonic acid in methyl alcoholic solution, and P_2S_5 in toluene produces thiosuccinanil,



$\begin{matrix}CH_2.CO\\ |\\ CH_2.CS\end{matrix}\!\!>\!N.C_6H_5$, m.p. 167°, which is split by alkalis into *thiosuccinanilic acid,* $HOCO.CH_2CH_2CSNHC_6H_5$, m.p. 107° (B. **39**, 3303). unsym.-*Dimethyl Succinanilic Acid,* $CO_2HC(CH_3)_2CH_2CONHC_6H_5$, m.p. 189°.

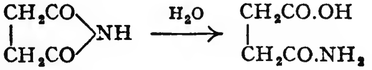
(*b*) **Imides.**—These are produced (1) on heating the acid anhydrides in a current of ammonia; (2) when the ammonium salts, diamides, and amido-acids are heated; (3) from the dinitriles, by partial hydration (C. 1902, I. 711). They show a symmetrical structure, as will be explained in connection with succinanil.



Succinimide, $\begin{matrix}CH_2.CO\\ |\\ CH_2.CO\end{matrix}\!\!>\!NH$, m.p. 126°, b.p. 288°, crystallizes with water, and has the character of an acid, as the hydrogen of the NH-group can be replaced by metals.

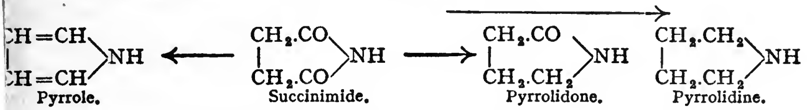
Potassium Succinimide, $C_2H_4(CO)_2NK$; *Sodium Succinimide* (B. **28**, 2353); *Silver Succinimide* (A. **215**, 200); *Potassium Tetrasuccinimide Tri-iodo-iodide,* $(C_4H_5O_2N)_4I_3.KI$ (B. **27**, R. 478; **29**, R. 298).

The cyclic imides are readily broken down by alkalis and alkaline earths:

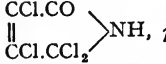


$$\begin{matrix}CH_2CO\\ |\\ CH_2CO\end{matrix}\!\!>\!NH \xrightarrow{H_2O} \begin{matrix}CH_2CO.OH\\ |\\ CH_2CO.NH_2\end{matrix}$$

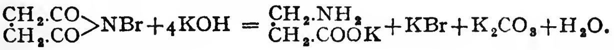
On distilling succinimide with zinc dust, pyrrole (p. 318) is formed; when heated with sodium in alcoholic solution it is converted into *tetramethylene imide* or *pyrrolidine* (p. 335). Electrolytic reduction produces *γ-butyrolactone* or *pyrrolidone* (p. 395).



Hypochlorous acid, and hypobromous acid acting on succinimide, and iodine on silver succinimide produce: *Succinochlorimide,* $C_2H_4(CO)_2NCl$, m.p. 148°; *Succinobromimide,* $C_2H_4(CO)_2NBr$, m.p. 174° with decomposition, and *Succiniodomide* (B. **26**, 985). Phosphorus pentachloride converts succinimide into *dichloro-*



maleïnimide chloride, $\begin{matrix}CCl.CO\\ \|\\ CCl.CCl_2\end{matrix}\!\!>\!NH$, *pentachloropyrrole,* C_4Cl_5N, and the *heptachloride,* C_4Cl_7N (A. **295**, 86). Bromine and potassium hydroxide convert succinimide into *β*-amidopropionic acid (p. 393):

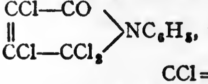
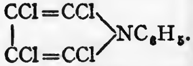
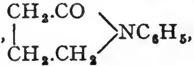


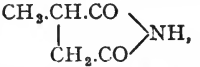
$$\begin{matrix}CH_2.CO\\ CH_2.CO\end{matrix}\!\!>\!NBr+4KOH=\begin{matrix}CH_2.NH_2\\ CH_2.COOK\end{matrix}+KBr+K_2CO_3+H_2O.$$

Sodium methoxide changes succinobromimide by a molecular rearrangement into *Carbomethoxy-β-amidopropionic Ester*, $CH_3O.CO.NHCH_2CH_2CO_2CH_3$, m.p. 33·5° (B. **26**, R. 935).

Methyl Succinimide, $C_2H_4(CO)_2N.CH_3$, m.p. 66·5°, b.p. 234°, is obtained from the oxime of lævulinic acid (p. 421) by the action of concentrated sulphuric acid (A. **251**, 318).

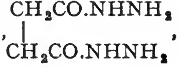
Ethyl Succinimide, m.p. 26°, b.p. 234°, is formed when ethyl iodide acts on potassium succinimide. It yields ethyl pyrrole when it is distilled with zinc dust. *Isopropyl Succinimide,* m.p. 61°, b.p. 230°. *Isobutyl Succinimide,* m.p. 28°, b.p. 247° (B. **28**, R. 600).

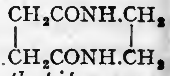
Phenyl Succinimide, Succinanil, $C_2H_4(CO)_2.N.C_6H_5$, m.p. 150°, is converted by PCl_5 into dichloromaleïc anil dichloride,  $\begin{array}{l}CCl—CO\\ \|\\ CCl—CCl_2\end{array}\!>NC_6H_5$, the lactam of γ-anilidoperchlorocrotonic acid and tetrachlorophenyl pyrrole,  $\begin{array}{l}CCl{=}CCl\\ |\\ CCl{=}CCl\end{array}\!>NC_6H_5$. This last fact, and the reduction of dichloromaleïc dichloride to γ-anilidobutyrolactam or n-phenyl butyrolactam,  $\begin{array}{l}CH_2.CO\\ |\\ CH_2.CH_2\end{array}\!>NC_6H_5$, indicate that the symmetrical formula properly represents both succinanil and succinimide (A. **295**, 39, 88).

Pyrotartrimide,  $\begin{array}{l}CH_3.CH.CO\\ \quad|\\ \quad CH_2.CO\end{array}\!>NH$, m.p. 66°. n-*Alkyl Pyrotartrimide* (B. **30**, 3039). sym.-*Dimethyl Succinimide* (B. **22**, 646). unsym.-*Dimethyl Succinimide,* m.p. 106°, is obtained by heating *aa*-dimethyl succinonitrile acid (C. 1899, I. 873); also by oxidation of *mesitylic acid* (A. **242**, 208; B. **14**, 1075). unsym.-*Dimethyl Succinanil,* m.p. 85°. *Trimethyl Succinanil,* m.p. 129°. *Tetramethyl Succinanil,* m.p. 88° (A. **285**, 234; **292**, 176, 184). *Pimelimide,* m.p. 60° (A. **220**, 276).

(*c*) **Diamides and Hydrazides.**

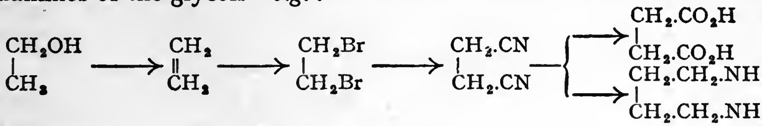
Succinamide, $NH_2CO.CH_2CH_2CONH_2$, is produced like oxamide. It crystallizes from hot water in needles. At 200° it decomposes into ammonia and succinimide.

Succinodibromodiamide, $NH_2CO[CH_2]_2CONBr_2$, is obtained from succinamide and KBrO (see also β-Lactyl Urea, p. 444). *Pyrotartramide,* m.p. 225° (B. **29**, R. 509). *Succinohydrazide,*  $\begin{array}{l}CH_2CO.NHNH_2\\ |\\ CH_2CO.NHNH_2\end{array}$, m.p. 167° (J. pr. Ch. [2] **51**, 190; B. **39**, 3376).

(*d*) **Cyclic Diamides.**—*Ethylene Succinyl Diamide,*  $\begin{array}{ll}CH_2CONH.&CH_2\\ |&|\\ CH_2CONH.&CH_2\end{array}$ (B. **27**, R. 589). *Succinophenylhydrazide,* 1-*Phenyl*-3,6-*Orthopiperazone,*  $\begin{array}{ll}CH_2CO.&N.C_6H_5\\ |&|\\ CH_2CO.&NH\end{array}$, m.p. 199°, is obtained from the hydrochloride of phenylhydrazine and succinyl chloride (B. **26**, 674, 2181); whilst succinic anhydride and phenylhydrazine yield the isomeric n-anilinosuccinimide $C_2H_4(CO)_2\ N.NHC_6H_5$, m.p. 155°.

(*e*) **Nitrilic Acids and Dinitriles.**—*Dimethyl Cyanopropionic Ester,* $CN.CH_2.C(CH_3)_2CO_2C_2H_5$, b.p. 218°, results when dimethyl cyanosuccinic mono-ethyl ester is heated (C. 1899, I. 874).

Dinitriles are produced from alkylene bromides (the addition products of bromine and the olefines) by treatment with potassium cyanide. Absorption of water converts these dinitriles into the ammonium salts of the corresponding acids, the synthesis of which they thus facilitate, When reduced, they take up eight atoms of hydrogen and become the diamines of the glycols—*e.g.*:



$$\begin{matrix} CH_2OH \\ | \\ CH_3 \end{matrix} \longrightarrow \begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} \longrightarrow \begin{matrix} CH_2Br \\ | \\ CH_2Br \end{matrix} \longrightarrow \begin{matrix} CH_2.CN \\ | \\ CH_2.CN \end{matrix} - \begin{cases} \longrightarrow \begin{matrix} CH_2.CO_2H \\ | \\ CH_2.CO_2H \end{matrix} \\ \longrightarrow \begin{matrix} CH_2.CH_2.NH_2 \\ | \\ CH_2.CH_2.NH_2 \end{matrix} \end{cases}$$

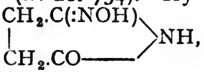
Succinonitrile, *Ethylene Cyanide*, $CN.CH_2CH_2.CN$, m.p. 54·5°, b.p.$_{20}$ 159°, is an amorphous, transparent mass (C. 1901, II. 807), readily soluble in water, chloroform and alcohol, but sparingly soluble in ether. It is also obtained by the electrolysis of potassium cyanacetate (p. 65).

It yields ethylene succinic acid when saponified, and tetramethylene diamine upon reduction. It combines with 4HI (B. **25**, 2543). Paraformaldehyde, glacial acetic acid and sulphuric acid convert it into *methylene succinimide*, $(C_2H_4.C_2O_2N)_2$-CH_2, m.p. above 270° (J. pr. Ch. [2] **50**, 3). When heated with water and sulphuric acid it forms succinimide (C. 1902, I. 711).

Pyrotartaric Nitrile, m.p. 12°, is obtained from allyl iodide and two molecules of KNC (A. **182**, 327; B. **28**, 2952).

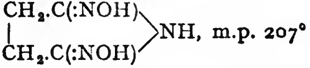
unsym-*Dimethyl Succinic Nitrile*, $CN.CH_2C(CH_3)_2CN$, b.p. 219° (B. **22**, 1740).

(*f*) **Oximes.**—*Succinyl Hydroxamic Acid*, $CO_2H.CH_2CH_2.C(:N.OH)OH$ (B. **28**, R. 999). *Succinyl Hydroxamic Tetracetate*, m.p. 130° (B. **28**. 754). Hydroxylamine converts succinonitrile into *Succinimidoxime*,



$$\begin{matrix} CH_2.C(:NOH) \\ | \\ CH_2.CO \end{matrix} \Big> NH,$$

m.p. 197° (B. **24**, 3427), and *Succinimide Dioxime*,



$$\begin{matrix} CH_2.C(:NOH) \\ | \\ CH_2.C(:NOH) \end{matrix} \Big> NH,$$

m.p. 207° (B. **22**, 2964).

HALOGEN SUBSTITUTION PRODUCTS OF THE SUCCINIC ACID GROUP

The *monosubstitution* products are obtained (1) by the direct action of halogens on the acids, their esters, chlorides or anhydrides. In case of the acids, it is advisable to act on them with amorphous phosphorus and bromine (B. **21**, R. 5); (2) by the addition of a halogen hydride to the corresponding unsaturated dicarboxylic acid of the *fumaric* and *maleïc* groups (A. **254**, 161); (3) by the action of a halogen hydride, and (4) of PCl_5 or PBr_5 on the corresponding α-monohydroxyethylene dicarboxylic acids (A. **130**, 21); (5) from aminosuccinic acids by means of potassium bromide, sulphuric acid, bromine and nitric oxide (B. **28**, 2769).

Inactive *Chlorosuccinic Acid*, $CO_2H.CHClCH_2.CO_2H$, m.p. 152°, is formed from fumaric acid and hydrochloric acid: *dimethyl ester*, b.p.$_{14}$ 106·5°; *diethyl ester*, b.p.$_{15}$ 122°; *anhydride*, m.p. 41°, b.p.$_{12}$ 126° (A. **254**, 156; B. **23**, 3757).

d-*Chlorosuccinic Acid*, m.p. 176° with decomposition, is obtained from l-malic acid by means of PCl_5 and water. Its silver salt is converted into d-malic acid when it is boiled with water; *dimethyl ester*, b.p.$_{15}$ 107°; *chloride*, b.p.$_{11}$ 92°; *anhydride*, b.p.$_{20}$ 138° (B. **28**, 1289).

l-*Chlorosuccinic Acid* is prepared from l-aspartic acid, which can be changed to l-malic acid. Starting, therefore, with l-aspartic acid, it is not only possible to prepare l-chlorosuccinic acid and l-malic acid, but with the aid of the latter we can obtain d-chlorosuccinic acid, which can be transposed into d-malic acid (p. 55):

$$\begin{tikzcd} & \text{l-Chlorosuccinic Acid} \arrow[d] & \text{d-Malic Acid} \arrow[l] \\ \textbf{l-Aspartic Acid} \arrow[ur] \arrow[r] & \text{l-Malic Acid} \arrow[r] & \text{d-Chlorosuccinic Acid.} \arrow[u] \end{tikzcd}$$

On the other hand, l-chloro- and l-bromo-succinic acid, which yield l-malic acid with silver oxide, give, with ammonia, d-aminosuccinic acid, from which d-malic acid can be obtained on boiling the substance with barium hydroxide solution (*Walden's Inversion*, pp. 55, 364, 388) (B. **30**, 2795):

$$\begin{tikzcd}
\text{l-Chlorosuccinic Acid} \arrow[r] \arrow[d] & \text{l-Malic Acid} \\
\text{d-Aminosuccinic Acid} \arrow[r] & \text{d-Malic Acid.}
\end{tikzcd}$$

Inactive *Bromosuccinic Acid*, $CO_2H.CHBrCH_2.CO_2H$, m.p. 160°, is prepared from hydrobromic acid and fumaric acid. It is decomposed by alkalis into its components (A. **348**, 261); *dimethyl ester*, b.p.$_{10}$ 110°; *anhydride*, m.p. 31°, b.p.$_{11}$ 137°.

d-Bromosuccinic Dimethyl Ester is formed from l-malic acid and PBr_5, b.p.$_{20}$ 124° (B. **28**, 1291).

l-*Bromosuccinic Acid*, is prepared from l-aspartic acid (B. **28**, 2770; **29**, 1699), m.p. 173° with decomposition.

Monoiodosuccinic Acid has only been obtained as a basic lead salt (B. **30**, 200).

The free, inactive acids and their esters, when heated at the ordinary pressure, break down into a halogen acid and fumaric acid and its ester, whilst the anhydrides yield the halogen hydride and maleïc anhydride (A. **254**, 157). Moist silver oxide converts bromosuccinic acid into *inactive malic acid* (*q.v.*), which can thus be synthesized in this way.

The addition of a halogen acid to ita-, citra-, and mesaconic acids produces *chloropyrotartaric acids*, $C_5H_7ClO_4$:

(1) *Itachloropyrotartaric Acid*, m.p. 140–141° (comp. Paraconic Acid and Itamalic Acid).

(2) *Mesa-* or *Citrachloropyrotartaric Acid*, m.p. 129° (A. **188**, 51; C. 1899, I. 1070).

Bromopyrotartaric Acids, $C_5H_2BrO_4$:

(1) *Itabromopyrotartaric Acid*, m.p. 137°.

(2) *Citrabromopyrotartaric Acid*, m.p. 148°.

Dihalogen Substitution Products are produced (1) by the direct action of bromine and water on the acids; (2) by the addition of halogen acids to the monohalogen unsaturated acids of the *fumaric* and *maleïc* series; (3) by the addition of halogens—particularly bromine—to the unsaturated acids of the fumaric and maleïc series.

When hydrobromic acid is added to fumaric and maleïc acids they yield the same monobromosuccinic acid, but with bromine, fumaric acid forms the sparingly soluble *dibromosuccinic acid*, whilst maleïc acid and bromine yield the easily soluble *isodibromosuccinic acid* and fumaric acid. These two dibromosuccinic acids have the same structural formula, they are symmetrical in arrangement, and their isomerism is probably due to the same cause prevailing with the dialkyl sym.-succinic acids (p. 494). Yet they are intimately related to racemic and mesotartaric acids, which were first synthetically prepared by means of the dibromosuccinic acids. Inasmuch as fumaric acid yields racemic acid when oxidized, therefore the sparingly soluble dibromosuccinic acid, the dibromo-addition product of fumaric acid, should correspond with racemic acid, and isodibromosuccinic acid with mesotartaric acid. However, the transposition reactions of the dibromosuccinic acids show many contradictions.

Dichlorosuccinic Acid, m.p. 215° with decomposition, is prepared from fumaric acids and liquid chlorine; *methyl ester*, m.p. 32° (A. **280**, 210).

Isodichlorosuccinic Acid, m.p. 170° with decomposition, is obtained from the *anhydride*, m.p. 95°, the addition product of maleïc anhydride and liquid chlorine. When heated, the anhydride changes to chloromaleïc anhydride (A. **280**, 216).

Dibromosuccinic Acid, $C_2H_2Br_2(CO_2H)_2$, consists of prisms which are not very soluble in cold water. When heated to 200–235° it breaks up into HBr and bromomaleïc acid; and with acetic anhydride it yields bromomaleïc anhydride and acetyl bromide; *methyl ester*, m.p. 62°; the *ethyl ester*, m.p. 68°.

Isodibromosuccinic Acid, $C_2H_2Br_2(CO_2H)_2$, m.p. 160°, is very soluble in water. It decomposes at 180° into HBr and bromofumaric acid (p. 514). Its *anhydride*, $C_2H_2Br_2(CO)_2O$, m.p. 42°, is formed from maleïc anhydride and bromine. At 100° it breaks down into HBr and bromomaleïc anhydride (A. **280**, 207). The *anilic acid*, m.p. 144°. The *anil*, m.p. 177° (A. **292**, 233; **239**, 143). When reduced, both acids yield ethylene succinic acid; when boiled with potassium iodide they change to fumaric acid, whilst boiling sodium hydroxide or barium hydroxide solutions convert them into *acetylene dicarboxylic acid* (A. **272**, 127). The sparingly soluble dibromo acid, when boiled with water, passes into bromomaleïc acid, whilst the readily soluble acid, under like treatment, becomes converted into bromofumaric acid. Two hundred parts of boiling water convert the difficultly soluble dibromo-acid, in the presence of the brominated unsaturated acid, into mesotartaric acid, together with a little racemic acid, whilst the readily soluble acid yields much racemic acid and but little of the mesotartaric acid (A. **292**, 295; **300**, 1).

The silver salt of the difficultly soluble dibromo-acid changes on boiling with water to mesotartaric acid (*q.v.*), whilst racemic acid is obtained under similar conditions from the easily soluble isodibromosuccinic acid (B. **21**, 268). Much *mesotartaric acid* with but little *racemic acid* is formed on boiling the barium or calcium salt of the difficultly soluble dibromosuccinic acid. The contradictions in these reactions are made clearer in the scheme which follows:

$$\begin{tikzcd}
\text{Fumaric Acid} \arrow[r, "KMnO_4"] \arrow[d] & \text{Racemic Acid.} \\
\text{Dibromosuccinic Acid} \arrow[r] \arrow[ur] & \text{Mesotartaric Acid (in quantity).}
\end{tikzcd}$$

$$\begin{tikzcd}
\text{Maleïc Acid} \arrow[r, "KMnO_4"] \arrow[d] & \text{Mesotartaric Acid.} \\
\text{Isodibromosuccinic Acid} \arrow[r] \arrow[ur] & \text{Racemic Acid (in quantity).}
\end{tikzcd}$$

Trichlorosuccinic Acid is a crystalline, exceedingly soluble mass, obtained on exposing chloromaleïc acid, water and liquid chlorine to sunlight (A. **280**, 230).

Tetrachlorosuccinanil, m.p. 157°, is formed together with dichloromaleïc anil chloride (p. 514), when PCl_5 acts on dichloromaleïc anil (A. **295**, 33).

Tribromosuccinic Acid, $C_2HBr_3(CO_2H)_2$, m.p. 136°, is produced when bromine and water act on bromomaleïc acid and isobromomaleïc acid. The aqueous solution decomposes at 60° into CO_2, HBr, and dibromacrylic acid, $C_3H_2Br_2O_2$ (p. 295). Alkalis convert it into dibromomaleïc acid; whilst excess of ammonia produces monobromofumaric acid (A. **348**, 264).

Dibromopyrotartaric Acids.—The addition of bromine to ita-, citra -and mesaconic acids gives rise to three dibromopyrotartaric acids, which upon reduction revert to the same pyrotartaric acid (p. 493).

The **ita-**, **citra-**, and **mesa-dibromopyrotartaric Acids**, $C_5H_6Br_2O_4$, are distinguished by their different solubility in water. The ita-compound changes to *aconic* acid, $C_5H_4O_4$, when the solution of its sodium salt is boiled; the citra- and mesa- compounds, on the other hand, yield *bromomethacrylic acid* (p. 297).

An excess of potassium hydroxide will convert citradibromopyrotartaric acid into bromomesaconic acid (p. 516).

GLUTARIC ACID GROUP

Glutaric acid and its alkyl derivatives, like ethylene succinic acid, are characterized by the fact that when heated they break down into the anhydride and water. The anhydrides readily yield anilic acids, from which anils can be obtained by the withdrawal of water. The glutaric acids resemble the ethylene succinic acids in behaviour, but they are changed to anhydrides with greater difficulty by acetyl chloride, and are not so volatile with steam.

Glutaric Acid, *Normal Pyrotartaric Acid* [Pentane Diacid]

$CH_2<\begin{matrix}CH_2CO_2H\\CH_2CO_2H\end{matrix}$, m.p. 97°, is isomeric with monomethyl succinic acid or ordinary pyrotartaric acid, as well as with ethyl and dimethyl malonic acids (p. 491). It was first obtained by the reduction of α-hydroxyglutaric acid with hydriodic acid. It may be synthetically prepared from trimethylene bromide (p. 322), through the cyanide;

from acetoacetic ester by means of the acetoglutaric ester (*q.v.*); from glutaconic acid (p. 520), and from propane tetracarboxylic acid or methylene dimalonic acid, $C_3H_4(CO_2H)_4$, by the removal of $2CO_2$; from hydroresorcinol and potassium hypobromite (B. **32**, 1871); by electrolysis of a mixture of potassium malonic ester and succinic ester (C. 1903, II. 1053). Glutaric acid crystallizes in large monoclinic plates, and distils near 303°, with scarcely any decomposition. It is soluble in 1·2 parts water at 14°.

The *calcium salt*, $C_5H_6O_4Ca+4H_2O$, and *barium salt*, $C_5H_6O_4Ba+5H_2O$, are easily soluble in water; the first is more readily in cold than in warm water (like calcium butyrate, p. 259); *monomethyl ester*, b.p.$_{20}$ 153° (B. **26**, R. 276; C. 1900, I. 169); *ethyl ester*, b.p. 237°.

The *anhydride*, $C_5H_6O_3$, m.p. 56–57°, forms on slowly heating the acid to 230–280°, and in the action of acetyl chloride on the silver salt of the acid.

Glutarimide, $C_3H_6(CO)_2NH$, m.p. 152°, is formed when ammonium glutarate is heated; when trimethylene cyanide (*q.v.*) is heated with sulphuric acid and water to 180–200° (C. 1902, I. 711), and by oxidation of pentamethylene imine (p. 336) or piperidine with H_2O_2 (B. **24**, 2777). When heated to redness with zinc dust, a little pyridine is formed (B. **16**, 1883).

Glutaric Peroxide, $O_2(COCH_2CH_2CH_2COOH)_2$, m.p. 108° with decomposition, is prepared from glutaric anhydride and H_2O_2. On being heated it yields a little suberic acid (p. 506) (C. 1904, II. 766).

Glutaric Dihydrazide, $(CH_2)_3(CONHNH_2)_2$, m.p. 176°. *Glutaric Diazide* is an explosive oil (J. pr. Ch. [2] **62**, 194).

Nitrile of Glutaric Acid, Trimethylene Cyanide, $CH_2{<}\begin{matrix}CH_2.CN\\CH_2.CN\end{matrix}$, m.p. −29°, b.p. 286° (C. 1901, II. 807), is obtained from trimethylene bromide and potassium cyanide. Alcohol and sodium convert it into pentamethylene diamine (p. 334) and piperidine (p. 336), whilst it yields glutarimide dioxime with hydroxylamine (B. **24**, 3431).

β-Chloroglutaric Acid is obtained from β-hydroxyglutaric acid. Diethylaniline converts it into glutaconic acid (p. 326) (C. 1905, I. 1225).

Pentachloroglutaric Acid, $CO_2H.CCl_2CHClCCl_2.CO_2H$ (B. **25**, 2219).

α-Bromo- and *α-Iodo-glutaric Ester* are converted by KOH or diethyl aniline into trimethylene dicarboxylic acid (comp. p. 507) (C. 1905, I. 1225).

αγ-Dibromoglutaric Acid, $CH_2(CHBrCOOH)_2$, *cis*-form, m.p. 170°; *trans*-form, m.p. 143° with decomposition (comp. p. 503, αγ-di-alkyl glutaric acids) result when glutaric acid is brominated, and by the oxidation of cis- and trans-dibromides of cyclopentadiene (Vol. II.). Reduction converts them into glutaric acid, whilst *αβ-Dibromoglutaric*, the *dibromide of glutaconic acid* (p. 520), yields glutaconic acid when reduced (A. **314**, 307, 509).

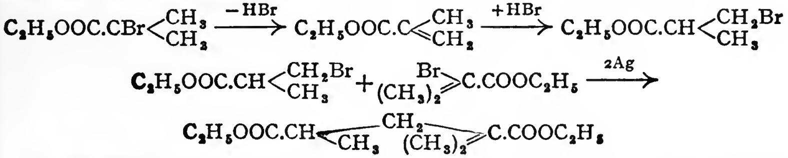
Mono-alkyl Glutaric Acids.—*α-Methyl Glutaric Acid*, $CH_2{<}\begin{matrix}CH_2COOH\\CH(CH_3)CO_2H\end{matrix}$, m.p. 76°, results from the reduction of saccharone, and on treating camphorphorone with $KMnO_4$ (B. **25**, 265). It may be synthesized from methyl acetoacetic ester and β-iodopropionic acid; and when KNC acts on lævulinic acid. It is a by-product in the decomposition of isobutylene tricarboxylic ester, the condensation product of bromisobutyric ester and alcoholic sodium malonate (see below). A series of α-alkyl glutaric acid are formed by the decomposition of the alkylated 1,1,3-propane tricarboxylic esters (C. 1901, I. 302), α-Methyl glutaric acid and P_2S_5 yield 3-*Methyl Penthiophen*; *anhydride*, m.p. 40°, b.p. 283°; *anilic acid* (A. **292**, 211); *dinitrile, α-methyl trimethylene cyanide*, b.p. 270°, is prepared from dibromobutane and KNC (C. 1902, II. 1097).

α-Ethyl Glutaric Acid, m.p. 60°, b.p.$_{30}$ 1905; *anhydride*, b.p. 275°; *anilic acid* (A. **292**, 144, 215).

β-Methyl Glutaric Acid, Ethylidene Diacetic Acid, $CH_3CH(CH_2CO_2H)_2$, m.p. 86°, is formed from crotonic ester and sodium malonic ester or sodium cyanacetic ester (C. 1906, I. 186); also from ethylidene dimalonic acid; *anhydride*, m.p. 46°, b.p. 283° (B. **24**, 2888). *β-Ethyl Glutaric Acid, Propylidene Diacetic Acid*, m.p. 67°, is prepared from propylidene dimalonic acid. *β-Isopropyl Glutaric Acid*, m.p.

100°, is formed from α-cyano-β-isopropyl glutaric mono-ester or β-isopropyl glutaric ester, whose methyl-substitution product yields *α-methyl β-isopropyl glutaric acid* (B. **38**, 947). The β-isopropyl glutaric acid, when oxidized with CrO_3, is converted into terpenylic acid (p. 558); but $KMnO_4$ produces terebic acid (p. 558) (C. 1899, I. 1157; 1900, II. 39, 467). The *dinitriles* of the β-alkyl glutaric acids are obtained also by boiling with water the oximes of alkylidene bis-pyroracemic acids (diketopimelic acids, $RCH[CH_2C(NOH)COOH]_2$ (C. 1906, I. 1105).

Di- and Tri-alkyl Glutaric Acids are produced together with tri- and tetramethyl succinic acids in the syntheses of these latter acids from α-bromisobutyric acid with silver, with methyl malonic ester, etc. In order to explain the formation of these unexpected alkyl glutaric acids in these reactions, it has been assumed that a portion of the α-bromisobutyric acid gives up HBr and passes into methacrylic ester. In the silver reaction the HBr attaches itself to the methyl acrylic ester, and the silver withdraws bromine from the α- and β-bromisobutyric esters, whereby the residues unite to trimethyl glutaric ester (B. **22**, 48, 60):

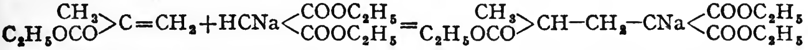


$$C_2H_5OOC.CBr<\begin{matrix}CH_3\\CH_2\end{matrix} \xrightarrow{-HBr} C_2H_5OOC.C\leqslant\begin{matrix}CH_3\\CH_2\end{matrix} \xrightarrow{+HBr} C_2H_5OOC.CH<\begin{matrix}CH_2Br\\CH_3\end{matrix}$$

$$C_2H_5OOC.CH<\begin{matrix}CH_2Br\\CH_3\end{matrix} + \begin{matrix}Br\\(CH_3)_2\end{matrix}\!\geqslant C.COOC_2H_5 \xrightarrow{2Ag}$$

$$C_2H_5OOC.CH<\begin{matrix}\quad CH_2 \quad\\ CH_3 \quad (CH_3)_2\end{matrix}\!\geqslant C.COOC_2H_5$$

In the second stage sodium methyl malonic ester attaches itself to methyl acrylic ester, and when the addition product is saponified it yields dimethyl glutaric acid (B. **24**, 1041, 1923):



$$\begin{matrix}CH_3\\C_2H_5OCO\end{matrix}\!>C=CH_2+HCNa<\begin{matrix}COOC_2H_5\\COOC_2H_5\end{matrix}=\begin{matrix}CH_3\\C_2H_5OCO\end{matrix}\!>CH-CH_2-CNa<\begin{matrix}COOC_2H_5\\COOC_2H_5\end{matrix}$$

The $\alpha\alpha_1$- (or $\alpha\gamma$-) and $\alpha\beta$-dialkyl glutaric acids, similarly to the sym.-dialkyl succinic acids (p. 494), exist in two modifications—the *para*- and *meso*-, or *cis*- and *trans*-forms. The *cis*- acids are easily converted into anhydrides and imides, whilst the *trans*-acids undergo these changes with difficulty or not at all (comp. C. 1903, I. 389, etc.).

$\alpha\alpha_1$-Dimethyl Glutaric Acid, $CH_2[CH(CH_3)CO_2H]_2$, m.p. *cis*- acid, 127°, *trans*-acid 140° (A. **292**, 146; B. **29**, R. 421), are also prepared from CH_2I_2 and sodium α-cyanopropionic ester. The *cis*-acid can also be obtained by reduction of $\alpha\alpha$-dimethyl glutaconic acid (p. 521) by means of HI and phosphorus, accompanied by the wandering of a methyl group (C. 1903, I. 697).

Bromine converts both acids into α-bromo-derivatives, from which hydroxy-dimethyl glutaric acids and their lactones are obtained (B. **25**, 3221; A. **292**, 146). Acetyl chloride or acetic anhydride convert the *cis*- acid into its *anhydride*, m.p. 94°, whilst the *trans*-acid is not changed when gently warmed (B. **31**, 2112). *$\alpha\alpha$-Dimethyl Glutaric Acids,* m.ps. 120° and 94°, are formed when β-hydroxy-diethyl-glutaric acid is reduced with HI (C. 1902, II. 107). On heating the barium salts of $\alpha\alpha_1$-dimethyl and -diethyl glutaric acids there result dimethyl tetramethylene ketone and diethyl tetramethylene ketone (C. 1897, II. 342). *$\alpha\alpha_1$-Methyl Isobutyl Glutaric Acids,* m.ps. 121° and 78°, are produced from sodium isobutyl malonic ester and bromisobutyl ester, etc. (C. 1900, II. 368).

$\alpha\beta$-Dimethyl Glutaric Acids, $CO_2H.CH(CH_3)CH(CH_3)CH_2CO_2H$, *trans*-acid fluid, *cis*-acid, m.p. 87°, are formed by hydrolysis and splitting off of CO_2 from the condensation products of crotonic ester, sodium cyanacetic ester and iodomethane; also of angelic or tiglic esters (p. 298) and sodium cyanacetic ester (C. 1903, I. 565, 1122; 1906, I. 186; comp. also A. **292**, 147; B. **29**, 2058).

unsym.-*$\alpha\alpha$-Dimethyl Glutaric Acid* $CO_2H.C(CH_3)_2CH_2CH_2CO_2H$, m.p. 85°; *anhydride,* m.p. 38°, is prepared from γ-chlorisobutyl acetic acid and potassium cyanide (C. 1898, II. 963; comp. C. 1902, II. 25); by reduction of the addition product of HI to $\alpha\alpha$-dimethyl glutaconic acid by means of zinc and hydrochloric acid; also by oxidation of camphor compounds (Vol. II.) (C. 1900, II. 282). Treatment of $\alpha\alpha$-dimethyl glutaric anhydride with Al_2Cl_6 in chloroform leads to a partial production of isocaprolactone and pyroterebic acid and CO_2 (comp. unsym.-dimethyl succinic anhydride (p. 496); also C. 1902, I. 567).

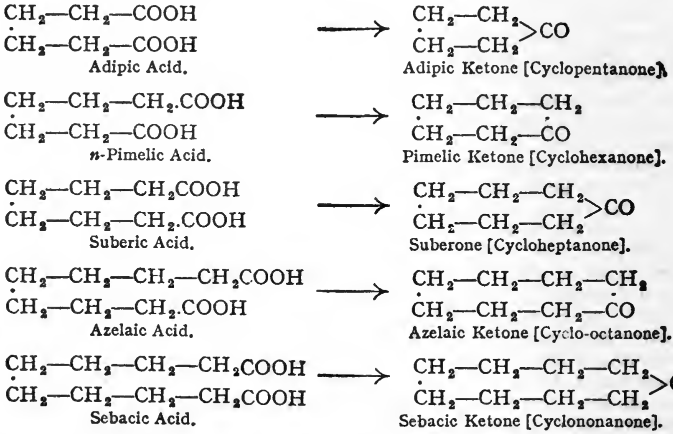
ββ-Dimethyl Glutaric Acid, $CO_2H.CH_2C(CH_3)_2CH_2CO_2H$, m.p. 104°; *anhydride*, m.p. 124°, is prepared from dimethyl acrylic ester with sodium or potassium malonic ester with subsequent decomposition of the dimethyl propane tricarboxylic ester which is formed (A. **292**, 145; C. 1897, I. 28); by decomposition of ββ-dimethyl propane tetracarboxylic ester (C. 1899, I. 926), of ββ-dimethyl $\alpha\alpha_1$-dicyanoglutaric ester or imide (C. 1901, I. 821); also by oxidation, by means of KBrO, of dimethyl hydroresorcinol (Vol. II.) (C. 1906, II. 18; B. **32**, 1879); *anilic acid*, m.p. 174°. Bromo-ββ-dimethyl glutaric ester and alcoholic potassium hydroxide yield the two *caronic* acids (Vol. II.). *ββ-Methyl Ethyl Glutaric Acid*, m.p. 87°. *ββ-Methyl Propyl Glutaric Acid*, m.p. 92°. *ββ-Methyl Butyl Glutaric Acid*, m.p. 65°. *ββ-Diethyl Glutaric Acid*, m.p. 108° (see C. 1901, I. 821).

$\alpha\alpha\alpha_1$-Trimethyl Glutaric Acid, $CO_2H_2CH(CH_3)CH_2C(CH_3)_2CO_2H$, m.p. 97° (comp. Tetramethyl Succinic Acid); *anhydride*, m.p. 96°, b.p. 262° (A. **292**, 220, C. 1906, II. 422). *αββ-Trimethyl Glutaric Acid*, m.p. 88°, is obtained from camphoric acid (Vol. II.), and α-cyano-αββ-trimethyl glutaric ester; *anhydride*, m.p. 82° (C. 1899, I. 522); α-cyano-$\alpha\alpha_1\beta\beta$-tetramethyl glutaric ester, produced by methylating α-cyano-αββ-trimethyl glutaric ester, yields the *$\alpha\alpha_1\beta\beta$-Tetramethyl Glutaric Acids*, $CO_2H.CH(CH_3)C(CH_3)_2CH(CH_3)CO_2H$, m.p. 140° and 90° (C. 1900, II. 466).

$\alpha\alpha\alpha_1\alpha_1$-Tetramethyl Glutaric Acid, $CH_2[C(CH_3)_2COOH]_2$, m.p. 186°, is produced from β-hydroxy-tetramethyl-glutaric acid by HI (C. 1900, II. 529).

GROUP OF ADIPIC ACID AND HIGHER NORMAL PARAFFIN DICARBOXYLIC ACIDS

Adipic acid, $CO_2H[CH_2]_4CO_2H$, and its alkyl derivatives volatilize under reduced pressure without decomposition. They, together with normal pimelic acid and suberic acid, are characterized by the fact (1) that when their calcium salts are heated *cyclic ketones* result (*J Wislicenus*, A. **275**, 309):



$$\begin{array}{l} CH_2—CH_2—COOH \\ CH_2—CH_2—COOH \end{array} \longrightarrow \begin{array}{l} CH_2—CH_2 \\ CH_2—CH_2 \end{array}\!\!>CO$$

Adipic Acid. Adipic Ketone [Cyclopentanone].

$$\begin{array}{l} CH_2—CH_2—CH_2.COOH \\ CH_2—CH_2—COOH \end{array} \longrightarrow \begin{array}{l} CH_2—CH_2—CH_2 \\ CH_2—CH_2—CO \end{array}$$

n-Pimelic Acid. Pimelic Ketone [Cyclohexanone].

$$\begin{array}{l} CH_2—CH_2—CH_2COOH \\ CH_2—CH_2—CH_2.COOH \end{array} \longrightarrow \begin{array}{l} CH_2—CH_2—CH_2 \\ CH_2—CH_2—CH_2 \end{array}\!\!>CO$$

Suberic Acid. Suberone [Cycloheptanone].

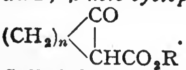
$$\begin{array}{l} CH_2—CH_2—CH_2—CH_2COOH \\ CH_2—CH_2—CH_2.COOH \end{array} \longrightarrow \begin{array}{l} CH_2—CH_2—CH_2—CH_2 \\ CH_2—CH_2—CH_2—CO \end{array}$$

Azelaic Acid. Azelaic Ketone [Cyclo-octanone].

$$\begin{array}{l} CH_2—CH_2—CH_2—CH_2COOH \\ CH_2—CH_2—CH_2—CH_2COOH \end{array} \longrightarrow \begin{array}{l} CH_2—CH_2—CH_2—CH_2 \\ CH_2—CH_2—CH_2—CH_2 \end{array}\!\!>CO$$

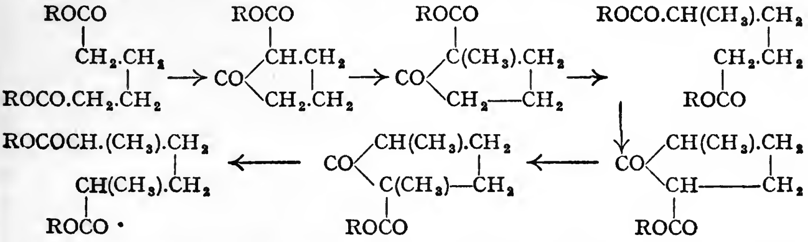
Sebacic Acid. Sebacic Ketone [Cyclononanone].

(2) *Cyclic Condensation* can also be brought about by the action of sodium or sodium amide on the esters of adipic, pimelic acid, and, to a lesser extent, suberic acid; *β-keto-cycloparaffin carboxylic esters* are formed having the general formula



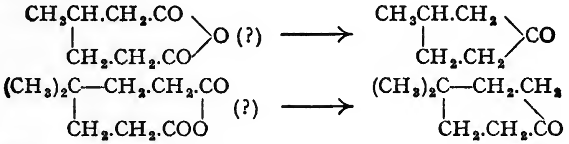
$$(CH_2)_n\!\!<\!\begin{array}{l} CO \\ | \\ CHCO_2R \end{array}.$$

Like acetoacetic ester, the CH-group can be alkylated by C_2H_5ONa and alkyl iodides, but when boiled with alcoholic sodium alcoholate the ring becomes broken, reforming the dicarboxylic esters. These reactions provide a *method for alkylating adipic and pimelic acids in the α-position* (A. **317**, 27; comp. C. 1905, II. 31; 1908, I. 1169), *e.g.*—



(3) Adipic acid and the higher normal paraffin dicarboxylic acids, similarly to succinic acid, tend to form anhydrides when boiled with acetyl chloride or acetic anhydride. The resulting bodies probably do not consist of single molecules, but are multiples of them (B. **27**, R. 1105; C. 1896, II. 1091; 1907, I. 964) (comp. also the anhydrides of dialkyl malonic acids, p. 491).

The anhydrides obtained from adipic and pimelic acids and their alkyl substitution products by boiling with acetic anhydride, decompose when distilled into CO_2 and cycloketones (C. 1907, II. 685):—



Adipic Acid [Hexane Di-acid], $CO_2H.[CH_2]_4CO_2H$, m.p. 148°, b.p.$_{10}$ 205·5°, was first obtained by the oxidation of fats (adeps = fat) by nitric acid. It can also be formed by the oxidation of cyclohexane, and particularly by oxidation of cyclohexanone or cyclohexanol, the products of reaction of phenol (Vol. II.) and alkaline potassium permanganate (B. **39**, 2202; **41**, 575). It can be prepared (1) by reduction of *hydromuconic acid* (p. 522); (2) synthetically, from β-iodopropionic acid and silver at 130–140°, or copper at 160° (B. **28**, R. 466); (3) from ethyl potassium succinate, by electrolysis (A. **261**, 177); (4) from ethylene dimalonic acid or butane tetracarboxylic acid; (5) by hydrolysis and splitting of γ-cyanopropyl malonic ester or of tetramethylene dicyanide (C. 1901, I. 218, 610; II. 807).

The action of sodium converts adipic ester into β-ketopentamethylene monocarboxylic acid ester. Distillation of the *calcium salt* or *anhydride* results in the production of cyclopentanone (p. 504). *Amide*, m.p. 222° (B. **32**, 1772). *Adipic Dinitrile, Tetramethylene Dicyanide*, m.p. 1°, b.p. 295°, is formed from tetramethylene bromide or iodide and KNC (C. 1901, I. 610; II. 807).

α-Methyl Adipic Acid, m.p. 64°. *α-Ethyl Adipic Acid* is a liquid. *β-Methyl Adipic Acid*, m.p. 89°, b.p.$_{14}$ 211°. It results from the oxidation of pulegone and menthone (A. **292**, 148); *ethyl ester*, b.p.$_{15}$ 138° $[\alpha]_D$ +2·24°. Condensation of the ester (see above) to *methyl cyclopentanone carboxylic ester* is accompanied by a great increase in the optical rotation to $[\alpha]_D$ +78·24° (C. 1905, II. 31), *α-Isopropyl Adipic Acid*, m.p. 67°, b.p.$_{12}$ 222° (C. 1908, I. 1169, 1616).

Dialkyl Adipic Acids are obtained (1) from cyclopentanone carboxylic esters, by alkylation and breaking of the ring (see p. 504); (2) from ethylene bis-alkyl malonic esters; (3) from lactones or the bromo-fatty acids corresponding with them, by the action of KNC or sodium malonic ester or sodium cyanacetic ester (comp. p. 477) (C. 1907, II. 897; 1908, I. 1616); (4) by oxidation of hydroaromatic ketones (Vol. II.); *αδ-Dimethyl Adipic Acid*, two modifications, m.ps. 143° and 76°; dinitriles are produced from the two 2,5-dibromohexanes (p. 323), by KNC (B. **34**, 807). *αα-Dimethyl Adipic Acid*, m.p. 90°. *ββ-Dimethyl Adipic Acid*, m.p. 87° (C. 1905, I. 26; 1907, I. 239; 1908, I. 1616). *αγ-Dimethyl Adipic Acid*, m.p. 80°. *α-Ethyl γ-Methyl Adipic Acid*, m.p. 98°. *αδ-Methyl Isopropyl Adipic Acid*, m.p. 111°, etc.

Normal Pimelic Acid [Heptane Diacid], $CO_2H[CH_2]_5CO_2H$, m.p. 105° (A. **292**, 150), was first prepared by oxidizing suberone; and from salicylic acid by the action of sodium in amyl alcohol solution; cyclohexanone results as an intermediate product, and the ring is broken according to the formulæ on p. 505 (A. **286**, 259); by heating furonic acid, $C_7H_8O_5$, with HI; and in the oxidation of fats with nitric acid. It can be obtained synthetically from trimethylene bromide and malonic ester by heating pentamethylene tetracarboxylic acid, which is the first product of the reaction (B. **26**, 709). It may be conveniently prepared from the *dinitrile, Pentamethylene Dicyanide*, $b.p._{12}$ 172°. This is obtained from crude dichloropentane (pp. 321, 323), and KNC (B. **37**, 3588; C. 1904, II. 587). When its calcium salt is distilled *pimelic ketone* [*cyclohexanone*] is produced (p. 504).

Alkyl Pimelic Acids: α-, β-, and *γ-Methyl Pimelic Acids*, m.p. 54°, 49°, and 56°. They are formed when the -o, m-, and p-cresotic acids (Vol. II.), or better their dibromo-derivatives, are reduced by amyl alcohol and sodium (A. **295**, 173). The α-acid may also be prepared from the corresponding tetracarboxylic acid (B. **29**, 729), and by acid decomposition of methyl ketohexamethylene carboxylic ester (p. 504).

$\alpha\alpha_1$-Dimethyl Pimelic Acids, m.p. 81° and 76° (B. **28**, R. 465).

αβα-Trimethyl Pimelic Acid, $b.p._{15}$ 214° (B. **28**, 2943).

ββ-Dimethyl Pimelic Acid, m.p. 104°, and *$\beta\beta\alpha_2$-Trimethyl Pimelic Acid*, m.p. 55°, are prepared from the condensation products of δ-bromo-β-dimethyl caproic ester and sodium malonic ester and sodium methyl malonic acid respectively. The *anhydrides* of these acids yield on distillation dimethyl cyclohexanone and trimethyl cyclohexanone (p. 505) (C. 1906, I. 1819; 1907, I. 964).

$\alpha\alpha_1$-Dibromopimelic Acid, m.p. 141°; *diethyl ester*, $b.p._{28}$ 224°, when acted on by sodium ethoxide becomes Δ'-cyclopentene dicarboxylic acid (Vol. II.).

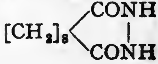
Suberic Acid [Octane Diacid], $CO_2H[CH_2]_6CO_2H$, m.p. 140°, is obtained by boiling cork (B. **26**, 3089), or fatty oils, with nitric acid (B. **26**, R. 814). Its *ethyl ester*, b.p. 280–282°, has been synthesized by electrolyzing potassium ethyl glutarate; it is also obtained by the action of magnesium and CO_2 on trimethylene bromide (p. 322) (B. **40**, 3039). Distillation of the calcium salt produces *suberone* (p. 504) (A. **275**, 356); *anhydride*, m.p. 62°; *diamide*, m.p. 216° (B. **31**, 2344); *dihydrazide*, m.p. 185°; *diazide*, m.p. 25°. See also 1,6-hexamethylene diamine (p. 334) (J. pr. Ch. [2] **62**, 198). *$\beta\beta_1$-Tetramethyl Suberic Acid*, $[HOOC.CH_2C(CH_3)_2.CH_2]_2$, m.p. 165°, is produced from β-dimethyl glutaric mono-ester, by electrolysis (C. 1906, II. 18).

Higher Paraffin-dicarboxylic Acids result, accompanied by oxalic, succinic and suberic acids, when fatty and oleic acids are oxidized by nitric acid.

The higher acetylene carboxylic acids (p. 304) usually decompose into the acids $C_nH_{2n}O_4$, when oxidized with fuming nitric acid. The mixture of acids that results is separated by fractional crystallization from ether; the higher members, being less soluble, separate out first (B. **14**, 560). Such acids have also been produced by the breaking-down of ketoximic acids through the action of concentrated sulphuric acid, *e.g.*, sebacic acid from ketoxime stearic acid (p. 300).

Lepargylic Acid, Azelaic Acid [Nonane Diacid], $CO_2H[CH_2]_7CO_2H$, m.p. 106°, is obtained by the oxidation of oleic acid and castor oil by nitric acid or permanganate (B. **17**, 2214; C. 1900, I. 250). The name is derived from azotic acid=nitric acid, and elaïdic acid, connected with oleic acid. It is synthetically prepared from pentamethylene bromide and sodium acetoacetic ester (B. **26**, 2249). When distilled with lime it yields azelaone (p. 504); *ethyl ester*, b.p. 291° (A. **307**, 375); *anhydride*, m.p. 52°; *nitrile*, $b.p._{21}$ 195° (C. 1898, II. 848). *Azelaïc Dithiolic acid*, COSH$[CH_2]_7$COSH, m.p. 73°, is formed when azelaïc diphenyl ester is "hydrolyzed" by NaSH. Sodium converts it into a *disulphide*, $[CH_2]_7[CO_2]S_2$ (C. 1905, II. 217).

Sebacic Acid [Decane Di-acid], $CO_2H[CH_2]_8CO_2H$, m.p. 133°, is formed (1) by dry distillation of oleic acid; (2) by oxidation of stearic acid, spermaceti or castor oil by nitric acid; (3) from stearyl ketoxime; (4) from heptane tetracarboxylic acid (B. **27**, R. 413). *Anhydride*, m.p. 78°; *diethyl ester*, $b.p._{20}$ 196°; *dihydrazide*, m.p. 185°; *diazide*, m.p. 34°. sym.-*Sebacic Hydrazide*



$$[CH_2]_8\left\langle\begin{matrix}CONH\\|\\CONH\end{matrix}\right.$$

m.p. 142° (J. pr. Ch. [2] **62**, 216).

Nonane Dicarboxylic Acid $[CH_2]_9(COOH)_2$, m.p. 110°, is obtained from ω-hydroxyundecylic acid (p. 375) by oxidation with CrO_3. *Decane Dicarboxylic Acid* $[CH_2]_{10}(COOH)_3$, m.p. 127°, is prepared from ω-bromo-undecylic acid and KNC; also synthetically by electrolysis of pimelic mono-ester (B. **34**, 900; C. 1901, II. 1046).

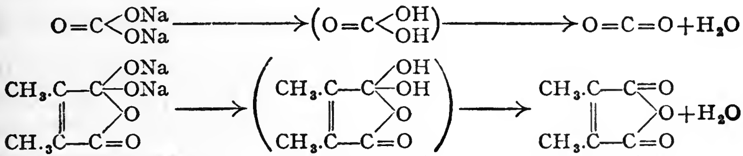
Brassylic Acid $[CH_2]_{11}(CO_2H)_2$, m.p. 114°, is obtained by oxidation of behenolic acid and erucic acid (B. **26**, 639, R. 705, 811). It is synthetically prepared by condensing *w*-bromo-undecylic ester and sodium malonic ester in alcohol, and subsequently hydrolysing and decomposing the condensation product. On the simultaneous formation of an isomeric acid (possibly *a-Methyl Decane Dicarboxylic Acid*), m.p. 82°, see B. **34**, 893 (comp. C. 1901, II. 1046).

Roccellic Acid, $C_{17}H_{32}O_4$, m.p. 132°, occurs free in nature in *Roccella tinctoria*.

B. OLEFINE DICARBOXYLIC ACIDS, $C_nH_{2n-4}O_4$

The acids of this series bear the same relation to those of the oxalic acid series that the acids of the acrylic series bear to the fatty acids.

The free acid hydrates of all the acids of the oxalic series are known, but in the case of the unsaturated acids there are some, like carbonic acid, which only exist in the anhydride condition. When the attempt is made to liberate the acids from their salts, they immediately split off water and pass into the corresponding anhydrides, *e.g.* dimethyl and diethyl maleïc anhydrides. The analogy of such acids with carbonic acid, to which reference has already been made (p. 307), shows itself in the following constitutional formulæ (A. **254**, 169; **259**, 137):—



$$O{=}C\Big\langle{}^{ONa}_{ONa} \longrightarrow \left(O{=}C\Big\langle{}^{OH}_{OH}\right) \longrightarrow O{=}C{=}O + H_2O$$

Sodium Pyrocinchonate or Dimethyl Malëate.

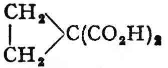
Pyrocinchonic Acid (does not exist).

Pyrocinchonic Anhydride.

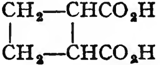
Hence, dimethyl and diethyl maleïc acids cannot contain two carboxyl groups any more than carbonic acid can contain them. Even in the salts and esters a γ-lactone ring would be present. The hypothetical acid hydrates would be unsaturated γ-dihydroxylactones.

The cycloparaffin dicarboxylic acids, having a like carbon content and isomeric with the unsaturated dicarboxylic acids, will be discussed after the cycloparaffins, *e.g.*:

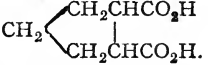
Trimethylene Dicarboxylic Acid,



Tetramethylene Dicarboxylic Acid,



Pentamethylene Dicarboxylic Acid,



The lowest member of the series has two possible structural isomers: *methylene malonic acid*, $CH_2{:}C(CO_2H)_2$, and *ethylene dicarboxylic acid*, $CO_2HCH{:}CH.CO_2H$. The first is only known in the form of its ester. However, there are two acids, *fumaric* and *maleïc acids*, which it is customary to regard as different modifications of ethylene dicarboxylic acid.

(*a*) Alkylidene Malonic Acids.

Methylene Malonic Ester, $CH_2{=}C(CO_2C_2H_5)_2$, is produced when 1 molecule of methylene iodide and 2 molecules of sodium ethoxide act on 1 molecule of malonic ethyl ester (together with *β-ethoxyisosuccinic ester*, $C_2H_5O.CH_2CH(CO_2R)_2$ (B. **23**, R. 194; **22**, 3294; A. **273**, 43). Under diminished pressure it distils as a mobile, badly-smelling oil. If allowed to stand, it soon changes into a white, solid mass, $(C_8H_{12}O_4)_2$ (C. 1898, II. 1169). The liquid ester unites with bromine. See also β-Hydroxyisosuccinic Acid, p. 550.

Ethylidene Malonic Ester, $CH_3CH{:}C(CO_2C_2H_5)$, b.p.$_{17}$ 116°, is formed when acetaldehyde is condensed with malonic ester by acetic anhydride (A. **218**, 145). Malonic ester combines with it to form *ethylidene dimalonic ester*. Hydrolysis with barium hydroxide solution converts it into a hydroxy-carboxylic acid, $C_3H_5(OH)(CO_2H)_2$. *Trichlorethylidene Malonic Ester*, $CCl_3CH : C(CO_2C_2H_5)_2$, b.p.$_{23}$ 160°, results when chloral and malonic ester are condensed by acetic anhydride (A. **218**, 145). ***Isopropylidene Malonic Acid***, $(CH_3)_2C : C(CO_2H_2)$, m.p. 170°; *ethyl ester*, b.p.$_{120}$ 176°, is formed from malonic ester and acetone by the action of acetic anhydride (B. **28**, 785, 1122, comp. B. **34**, 1955).

Cyanacetic ester, reacting with aldehydes in the presence of sodium ethoxide, gives rise to olefine nitrile esters, such as *ethylidene cyanacetic ester*, $CH_3CH{:}C(CN)CO_2R$ (C. 1901, I. 1271; comp. C. 1898, I. 664). Cyanacetic ester condensed with acetone by diethylamine, is converted into *Isopropylidene Cyanacetic Ester*, $(CH_3)_2C : C(CN)CO_2C_2H_5$, m.p. 28° (B. **33**, 3530; C. 1905, II. 726).

Allyl Malonic Acid, $CH_2{:}CH.CH_2CH(CO_2H)_2$, m.p. 103°, is obtained from malonic ester by means of allyl iodide. It crystallizes in prisms (A. **216**, 52). Compare γ-Valerolactone, p. 374, and Carbovalerolactonic Acid, p. 551. See B. **29**, 1856, and C. 1905, II. 660, for *Ethyl Allyl Malonic Acid* and its homologues.

(*b*) Unsaturated Dicarboxylic Acids, *in which the carboxyl groups are attached to two carbon atoms.*

Formation.—They can be obtained, like the acrylic acids, from the saturated dicarboxylic acids by the withdrawal of two hydrogen atoms. This is effected (1) by acting on the monobromo-derivatives with alkalis:

$$\underset{\text{Bromosuccinic Acid.}}{C_2H_3Br(CO_2H)_2} \xrightarrow{-HBr} \underset{\text{Fumaric Acid.}}{C_2H_2(CO_2H)_2};$$

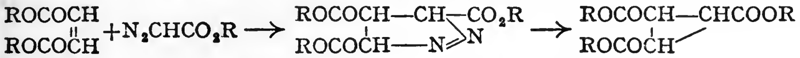
(2) by allowing potassium iodide to act on the dibromo-derivatives (p. 500). Thus, fumaric acid is formed from both dibromo- and isodibromo-succinic acids:

$$C_2H_2Br_2(CO_2H)_2+2KI=C_2H_2(CO_2H)_2+2KBr+I_2;$$

and mesaconic acid, $C_3H_4(CO_2H)_2$, from citra- and mesa-dibromopyrotartaric acids, $C_3H_4Br_2(CO_2H)_2$. As a general rule the unsaturated acids are obtained (3) from the hydroxydicarboxylic acids by the elimination of water (p. 509).

Behaviour.—The acids of this series show the same tendency to addition reactions as was observed with the unsaturated monocarboxylic acids. Thus (1) hydrogen causes them to revert to saturated dicarboxylic acids; (2) halogen acids (particularly HBr) and (3) halogens convert them into haloid saturated dicarboxylic acids. (4) When heated with potassium hydroxide an addition of hydrogen occurs with the production of monohydroxy-saturated dicarboxylic acids; others, again, are molecularly rearranged (B. **26**, 2082). Such rearrangement among isomers has been induced by boiling water or acids (comp. fumaric and maleïc acids, mesaconic, citraconic and itaconic acids). (5) Potassium permanganate oxidizes some of the unsaturated dicarboxylic acids to dihydroxy-dicarboxylic acids of the paraffin series. (6) Amino- and substituted amino-dicarboxylic acids of the saturated series have been obtained by the addition of ammonia, aniline and other bases.

(7) The acids of this series combine with diazomethane or diazoacetic acid, yielding pyrazoline derivatives (A. **273**, 214; B. **27**, 868), which pass into trimethylene derivatives by the elimination of nitrogen (p. 404):



Fumaric and *maleïc acids*, the first members of this series, are by far the most important acids of their class.

Fumaric Acid, $C_2H_2(CO_2H)_2$, occurs free in many plants, in Iceland moss, in *Fumaria officinalis*, and in some fungi. It is formed (1) when inactive and active malic acid are heated (water and maleïc anhydride are also produced) (B. **12**, 2281; **18**, 676), and by boiling malic acid with sodium hydroxide solution (B. **33**, 1453); (2) by boiling the aqueous solutions of monochloro- and monobromo-succinic acids; (3) by heating dibromo- and isodibromo-succinic acids with a solution of potassium iodide; (4) synthetically from dichlor- or dibromacetic acid and silver malonate; also from glyoxylic acid and malonic acid by heating them with pyridine (B. **34**, 53); (5) from maleïc acid (see the conversion of fumaric and maleïc acids into each other, p. 511); and fumaric acid is obtained by boiling with water bromosuccinyl bromide, the reaction product of phosphorus and bromine on succinic acid (B. **23**, 3757).

Properties.—It is almost insoluble in cold water, but crystallizes from hot water in small, striated prisms. It sublimes at 200°, and at higher temperatures decomposes, forming maleïc anhydride and water.

Salts.—The *silver salt*, $C_4H_2O_4Ag_2$, is very insoluble; it is fairly stable under the influence of light; *barium salt*, $C_4H_2O_4Ba+3H_2O$, consists of prismatic crystals, which effloresce and when boiled with water change to $C_4H_2O_4Ba$—a salt that is practically insoluble in water.

Esters—The fumaric esters are formed (1) from the silver salt and alkyl iodides; (2) from fumaric acid, alcohols and hydrochloric acid; (3) from the esters of monobromosuccinic acid by the action of pyridine or quinoline (C. 1905, I. 25); by the slow distillation of malic and acetyl malic esters (B. **22**, R. 813); (4) from maleïc esters (see interchange between fumaric and maleïc acids, p. 511); (5) by heating diazoacetic esters (B. **29**, 763).

The *methyl ester*, $C_2H_2(CO_2CH_3)_2$, m.p. 102°, b.p. 192°; *ethyl ester*, b.p. 218° (B. **12**, 2283). Bromine unites with fumaric esters to form dibromosuccinic esters.

Many other substances have the power of adding themselves to them, *e.g.* sodium acetoacetic ester, sodium malonic ester (B. **24**, 309, 2887, R. 636), sodium cyanacetic ester (B. **25**, R. 579), diazoacetic ester (above) phenyl azoimide, etc.

Fumaryl Chloride, COCl.CH:CH.COCl, b.p. 160°, is produced when PCl_5 acts on fumaric acid (B. **18**, 1947; C. 1906, II. 19). Bromine converts it into dibromosuccinyl chloride (A. Suppl. **2**, 86); and with sodium peroxide it yields *Fumaric Peroxide*, $C_4H_2O_4$, a white powder, exploding at 80° (B. **29**, 1726).

Fumaramic Acid, $CONH_2.CH:CH.CO_2H$, m.p. 217°. is formed when asparagine is acted on by methyl iodide and potassium hydroxide (A. **259**, 137).

Fumaramide, $CONH_2CH{=}CH.CONH_2$, m.p. 266° (B. **25**, 643).

Fumarhydrazide, $NH_2NH.CO.CH{:}CH.CO.NHNH_2$, m.p. 220°, with decomposition. *Fumarazide*, $N_3CO.CH{:}CH.CON_3$, is crystalline. It explodes easily, and when boiled with alcohol yields *Fumarethyl Urethane*, ROCONHCH:-CHNHCOOR (B. **29**, R. 231).

Fumaranilic Acid, $C_6H_5NH.COCH{=}CH.CO_2H$, m.p. 231°, is formed from the corresponding chloride and water. *Fumaranilic Chloride*, $C_6H_5NH.CO.CH{=}CH.COCl$, m.p. 120°, crystallizes from ether in transparent, strongly refracting, sulphur-yellow coloured prismatic needles or plates. It is produced when aniline acts on fumaryl chloride in excess. *Fumardianilide*, $C_6H_5NHCOCH{=}CHCONHC_6H_5$, m.p. 234°, with decomposition (A. **239**, 144; C. 1906, II. 19).

Maleïc Acid, $C_4H_4O_4$, m.p. 130°, b.p. 160° with decomposition into maleïc anhydride and water. Its anhydride is formed as mentioned under fumaric acid:

(1) By the rapid heating of malic acid.

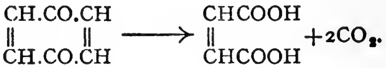
(2) In the slow distillation of monochloro- and monobromosuccinic acid, as well as acetyl malic anhydride at the ordinary pressure.

(3) By the action of PCl_5 on malic acid (A. **280**, 216).

(4) Maleïc acid is formed synthetically, in small amount, when silver or sodium acts on dichloracetic acid and dichloracetic ester.

(5) Maleïc acid is obtained on decomposing trichlorophenomalic acid or β-trichloracetyl acrylic acid (p. 425) with barium hydroxide solution. Chloroform is produced at the same time.

(6) From quinone (Vol. II.) by oxidation with silver peroxide (B. **39**, 3715):



$$\begin{array}{l} CH.CO.CH \\ \|\qquad\quad\ \| \\ CH.CO.CH \end{array} \longrightarrow \begin{array}{l} CHCOOH \\ \| \\ CHCOOH \end{array} + 2CO_2.$$

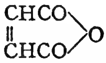
(7) From fumaric acid (see transformations of fumaric and maleïc acids).

Properties.—Maleïc acid crystallizes in large prisms or plates, is very easily soluble in cold water, and possesses a peculiar, disagreeable taste.

Salts.—$C_4H_2O_4Ag_2$ is a finely divided precipitate. It gradually changes to large crystals. $C_4H_2O_4Ba+H_2O$ is soluble in hot water, and crystallizes well.

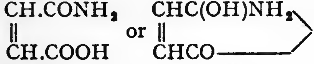
The *esters* result from the action of alkyl iodides on the silver salt:

The *methyl ester*, $C_2H_2(CO_2.CH_3)_2$, is a liquid, b.p. 205°; *ethyl ester*, b.p. 225°. When heated with iodine they change for the most part into fumaric esters.

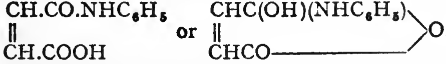


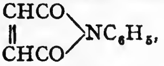
Maleïc Anhydride, $\begin{array}{l} CHCO \\ \| \\ CHCO \end{array}\!\!>O$, m.p. 53°, b.p. 202°, is produced (1) by distilling maleïc or fumaric acid alone, or more readily (2) with acetyl chloride or P_2O_5 (B. **37**, 3722); (3) by the distillation of monochloro- and monobromosuccinic acids, and also of acetomalic anhydride (A. **254**, 155); (4) when PCl_5, P_2O_5 and $POCl_3$ act on fumaric acid (A. **268**, 255). It is purified by crystallization from chloroform (B. **12**, 2281; **14**, 2546). It consists of needles or prisms, having a faintly penetrating odour. It regenerates maleïc acid by union with water, and forms isodibromosuccinic anhydride when heated with bromine (comp. Asparagine, p. 554).

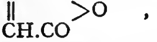
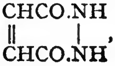
Maleïc Chloride (B. **18**, 1947; C. 1906, II. 20).

Maleïnamic Acid,  $\begin{matrix}CH.CONH_2\\ \|\\ CH.COOH\end{matrix}$ or $\left.\begin{matrix}CHC(OH)NH_2\\ \|\\ CHCO\text{———}\end{matrix}\right\rangle O$, m.p. 153°. Its ammonium salt results when ammonia acts on maleïc anhydride. Aqueous potassium hydroxide converts the acid into maleïc acid, whereas fumaric acid results when it is treated with alcoholic potassium hydroxide. *Maleïnmethylamic Acid,* m.p. 149° (B. **29**, R. 653).

Maleïnimide, $C_2H_2(CO)_2NH$, m.p. 93°, is produced when pyrrole is oxidised by chromic acid mixture. It sublimes when heated (C. 1904, II. 305).

Maleïnanilic Acid,  $\begin{matrix}CH.CO.NHC_6H_5\\ \|\\ CH.COOH\end{matrix}$ or $\left.\begin{matrix}CHC(OH)(NHC_6H_5)\\ \|\\ CHCO\text{————}\end{matrix}\right\rangle O$. m.p. 187°, is formed when aniline acts on an ethereal solution of maleïc anhydride. Heated under greatly reduced pressure it splits into maleïc anhydride and aniline, which reunite in the receiver to maleïnanilic acid. Alcoholic potassium hydroxide and barium hydroxide solution convert it into fumaric acid (A. **259**, 137).

Maleïnanil,  $\left.\begin{matrix}CHCO\\ \|\\ CHCO\end{matrix}\right\rangle NC_6H_5$, m.p. 91°, results upon heating aniline malate, in the form of bright yellow needles. It combines readily with aniline, forming phenyl asparaginanil (A. **239**, 154). *Maleïndianilide,* m.p. 175° (C. 1901, I. 171).

Aminomaleïnimide,  $\left.\begin{matrix}CH.C{=}N.NH_2\\ \|\\ CH.CO\end{matrix}\right\rangle O$, m.p. 111°, is obtained from maleïc anhydride and hydrazine hydrate in alcohol. When its solution is heated it changes to *Maleïn Hydrazide,*  $\begin{matrix}CHCO.NH\\ \|\quad\quad |\\ CHCO.NH\end{matrix}$, consisting of white crystals, which do not melt at 250°. It is a strong acid.

BEHAVIOUR OF FUMARIC AND MALEÏC ACIDS

1. Acetylene is formed when the alkali salts of these acids are electrolyzed (p. 86).
2. Sodium amalgam, or zinc, reduces them both to succinic acid.
3. When heated to 100° with sodium hydroxide both acids change to inactive malic acid (A. **269**, 76), whilst malic acid is changed into fumaric acid when boiled with sodium hydroxide solution (p. 509).
4. Fumaric and maleïc esters react with sodium alcoholates to form alkylhydroxy-succinic acids (B. **18**, R. 536).
5. Bromine converts:

Fumaric acid	into *dibromosuccinic acid.*
Fumaric ester	,, *dibromosuccinic ester.*
Fumaryl chloride	,, *dibromosuccinyl chloride.*
Maleïc anhydride	,, *isodibromosuccinic anhydride.*

6. Potassium permanganate changes (B. **14**, 713):

Fumaric acid	into *racemic acid.*
Maleïc acid	,, *mesotartaric acid.*

CONVERSION OF FUMARIC AND MALEIC ACIDS INTO EACH OTHER

1. When fumaric acid is heated, or treated with PCl_5, $POCl_3$ and P_2O_5 (A. **268**, 255; **273**, 31) it becomes converted maleïc anhydride.
2. Maleïc acid changes to fumaric acid:

(*a*) When it is heated alone in a sealed tube to 200° (B. **27**, 1365).

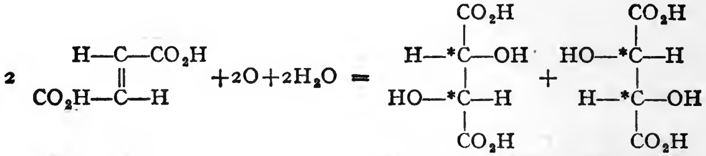
(*b*) By the action of cold HCl, HBr, HI and other acids; also SO_2 and H_2S (B. **24**, R. 823), H_2O_2 (B. **33**, 3241), as well as by the action of bromine in sunlight (B. **29**, R. 1080) (*c*) On heating maleïc ester with iodine fumaric esters result.

(*d*) Alcoholic potassium hydroxide changes maleïnamic and maleïnanilic acids to fumaric acid.

THE ISOMERISM OF FUMARIC AND MALEÏC ACIDS

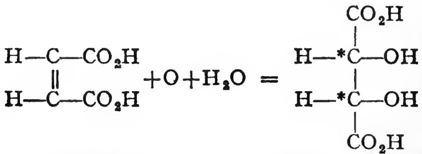
The view generally acepted as to the cause of the isomerism of these two acids was presented in the introduction, under the section relating to the geometrical isomerism, the stereoisomerism of the ethylene derivatives (p. 32). In conformity with this representation we find in maleïc acid, readily forming an anhydride, an atomic grouping which follows the plane-symmetrical configuration, according to which the carboxyl groups are so closely arranged with reference to each other that the production of an anhydride follows without difficulty. Fumaric acid is not capable of forming an anhydride, hence it has the central or axial symmetrical structure.

These space-formulæ satisfactorily represent the intimate connection existing, as shown by *Kekulé* and *Anschütz*, between fumaric and racemic acids, and maleïc and inactive tartaric acids. According to the *van 't Hoff-Le Bel* view of these four acids, the oxidation of fumaric to racemic acid by means of potassium permanganate and maleïc to mesotartaric acid, may be shown by the following formulæ, which have a spacial significance (comp. p. 32):—



$$2\ \begin{array}{c} H-C-CO_2H \\ \| \\ CO_2H-C-H \end{array} + 2O + 2H_2O = \begin{array}{c} CO_2H \\ | \\ H-{}^*C-OH \\ | \\ HO-{}^*C-H \\ | \\ CO_2H \end{array} + \begin{array}{c} CO_2H \\ | \\ HO-{}^*C-H \\ | \\ H-{}^*C-OH \\ | \\ CO_2H \end{array}$$

Fumaric Acid. **Dextro-tartaric Acid + Lævo-tartaric Acid = Racemic Acid.**



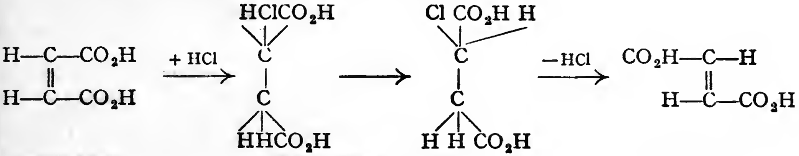
$$\begin{array}{c} H-C-CO_2H \\ \| \\ H-C-CO_2H \end{array} + O + H_2O = \begin{array}{c} CO_2H \\ | \\ H-{}^*C-OH \\ | \\ H-{}^*C-OH \\ | \\ CO_2H \end{array}$$

Maleïc Acid. **Mesotartaric Acid.**

The oxidation of the two acids, based on stereochemical formulæ, is so represented that upon severing the double linkage in fumaric acid by the addition of hydroxyl groups an equal number of molecules of dextro- and lævo-tartaric acid results, whilst by the rupture of the double linkage in maleïc acid only mesotartaric acid is formed.

Cognizant of this view, *J. Wislicenus* has sought to explain the conversion of maleïc into fumaric acid by hydrochloric acid in the following manner: In these two acids the two doubly-linked carbon atoms cannot rotate independently of each other, consequently not in opposite directions; but when the double union is removed by the addition of two univalent atoms, then free rotation at the single bond can occur. Accordingly, *J. Wislicenus'* explanation proceeds, in his own words, as follows: "On account of the extreme ease with which maleïc acid, in contrast to fumaric acid, lends itself to the formation of addition products

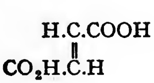
(B. **12**, 2282), it first absorbs the elements of the mineral acids (*e.g.*, HCl), and becomes converted into a substituted succinic acid, which, under the directing influence of the greater affinities, assumes the preferred configuration (in which similar groups are as far removed from each other as possible) by the rotation of the one system in opposition to the other, and then by the loss of HCl, under the influence partly of the water which is present and partly of the slight solubility of fumaric acid, the latter acid must result."



Maleïc Acid. Monochlorosuccinic Acid previous to rotation; after rotation in the preferred position. **Fumaric Acid.**

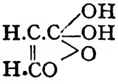
Only that intermediate product, monochlorosuccinic acid, is known in the free condition, which is in the preferred configuration. It is stable towards hydrochloric acid at 10°, and its anhydride unites with water to form the original acid, instead of yielding fumaric acid, although in so doing the monochloroscuccinic acid, as predicted by *J. Wislicenus*, in the conversion of maleïc into fumaric acid would change, through rotation, from the less favourable to the preferred configuration (*Anschütz*, A. **254**, 168). This is by no means the only fact with which the preceding explanation of the mechanism of the reactions showing the conversion of fumaric into maleïc acid, and vice versâ, clashes (comp. B. **20**, 3306; **24**, R. 822; **24**, 3620; **25**, R. 418; **26**, R. 177; A. **259**, 1; **280**, 226; J. pr. Ch. [2] **75**, 105; see also Z. phys. Ch. **48**, 40).

In the introduction to the unsaturated dicarboxylic acids it was shown that at least some of these acids could only exist in the anhydride form, as their hydrated forms broke down, in the moment of their liberation from salts, into anhydrides and water. These acids, the dialkyl maleïc acids (p. 518), are intimately related to maleïc acid. The monoalkyl acids (p. 516) are still capable of existing in hydrate form, although they change more easily than maleïc acid to their anhydrides. Considering the analogy with carbonic acid, the salts of the dialkyl maleïc acids may be viewed as being derivatives of a hypothetical acid hydrate, in which the two hydroxyl groups are attached to the same carbon atom, and this view may be considered to prevail with maleïc acid and with the monoalkyl maleïc acids, so similar to the dialkyl maleïc acids. The assumption that fumaric acid is symmetrical ethylene dicarboxylic acid and maleïc acid the γ-dihydroxyl-actone corresponding with this dicarboxylic acid in no wise renders a stereochemical formulation of the two acids impossible. Probably the stereochemically different arrangement and position, in the chemical structure, of the atoms contained in both acids, mutually influence each other (A. **254**, 168):



$$\begin{array}{c} \mathrm{H.C.COOH} \\ \| \\ \mathrm{CO_2H.C.H} \end{array}$$

Fumaric Acid.



Maleïc Acid.

However, even this view, as yet, does not afford a satisfactory explanation of the reactions by which these acids are converted into each other. Consult A. **239**, 161, for the history of the isomerism of fumaric and maleïc acids.

The various ideas as to the cause of the isomerism of fumaric and maleïc acids are connected with the question as to the nature of the double linkage (p. 35).

Finally, attention may be directed to the difference in the heat of combustion of the acids. This would indicate that the energy present in the acids, in the form of atomic motion, is markedly different. "This fact suggests the possibility that the cause of the isomerism is not to be sought exclusively in the varying arrangement of the atoms, nor in their different spacial positions, but also in the varying magnitude of the motion of the atoms (or atom complexes)." "It is also possible to imagine a case in which the isomerism would only be influenced by the difference in energy content—a case in which there might be perfect similarity in linkage and also in the spacial arrangement of the atoms."

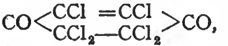
In addition to structural and spacial isomerism, there is the hypothesis of *energy* or *dynamical isomerism* (*Tanatar*, A. **273**, 54; B. **11**, 1027; **29**, 1300), to which this name is more applicable than to that to which attention has been drawn in connection with the sym.-dialkyl succinic acids (p. 494). *Klinger* proposes the name "alloergatia" (from crgasia or ergatia) for that type of isomerism when molecules of the same weight and chemical construction contain unequal quantities of energy (B. **32**, 2194).

It is by no means established that fumaric acid is not a polymeric modification of maleïc acid. That their vapour densities are the same proves nothing on this point, inasmuch as the vapour densities of racemic and tartaric esters are identical, and yet the molecule of solid racemic acid consists of a molecule each of dextro- and lævo-tartaric acids. The same remarks are true in regard to the results obtained by the freezing-point depressions.

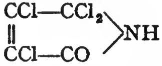
Haloid Fumaric and Maleïc Acids

Monochlorofumaric Acid, $C_4H_3ClO_4$, m.p. 192°, results (1) from tartaric acid and PCl_5 or PCl_3; (2) from the two dichlorosuccinic acids; (3) from acetylene dicarboxylic acid and fuming nitric acid. *Monochloromaleïc Acid*, m.p. 106°; *anhydride*, m.p. 0° and 34°, b.p.$_{760}$ 197°, b.p.$_{25}$ 95°, is produced when acetyl chloride acts on chlorofumaric acid, and when isodichlorosuccinic anhydride is heated (A. **280**, 222).

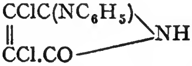
Monobromofumaric Acid, $C_4H_3BrO_4$, m.p. 179°, is produced from acetylene dicarbonic acid and HBr; and from isodibromosuccinic acid and boiling water. *Monobromomaleïc Acid*, m.p. 128°, is formed when dibromosuccinic acid—the addition product of bromine and fumaric acid—is boiled with water; *ester*, b.p.$_{12}$ 140°, is prepared from dibromosuccinic ester and quinoline (C. 1905, I. 26); *anhydride*, b.p. 215°, is prepared by heating isodibromosuccinic anhydride and dibromosuccinic acid, either alone or with acetic anhydride or acetyl chloride. The action of HBr is to produce bromofumaric acid and some dibromosuccinic acid. *Monoiodofumaric acid*, m.p. 183° (B. **15**, 2697).

Dichloromaleïc Acid, $C_4Cl_2H_2O_4$, results when *hexachloro-p-diketo-R-hexene*,  $CO<\begin{matrix}CCl=CCl\\CCl_2-CCl_2\end{matrix}>CO$, and *perchloracetyl acrylic acid*, $CCl_3CO.CCl{=}CCl.CO_2H$ (p. 425), are decomposed by sodium hydroxide (A. **267**, 20; B. **25**, 2230). On the application of heat it passes into the *anhydride*, $C_2Cl_2(CO)_2O$, m.p. 120°. PCl_5 converts succinic chloride into two isomeric *dichloromaleïc chlorides* (B. **18**, R. 184; C. 1900, I. 404). Its *imide*, $C_2Cl_2(CO_2)_2NH$, m.p. 179°, is obtained when succinimide is heated in a current of chlorine. One molecule of PCl_5 changes the imide to *Dichloromaleïnimide Chloride* (1), m.p. 148°, which is also formed from PCl_5 and succinimide. Aniline converts it into *dichloromaleïnimide anil* (2), m.p. 152°. Two molecules of PCl_5 transform dichloromaleïnimide into *pentachloropyrrole* (3), b.p.$_{10}$ 90·5°:

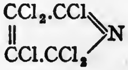
(1)



(2)

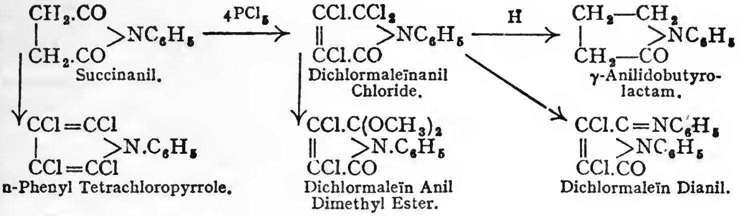


(3)



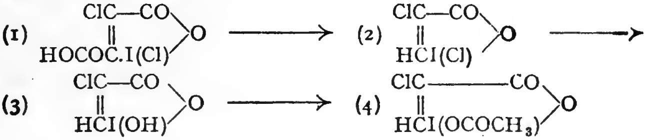
Dichloromaleïn Anil, $C_2Cl_2(CO)_2NC_6H_5$, m.p. 203°, is formed when dichloromaleïn anil chloride is boiled with glacial acetic acid or water.

Dichloromaleïn Anil Chloride, m.p. 124°, b.p.$_{11}$ 179°, is produced, together with *Tetrachloro-n-phenyl Pyrrole*, m.p. 93°, on treating succinanil with PCl_5. By reduction it yields δ-anilidobutyrolactam (see Succinimide, p. 497). Alcohols convert it into dialkyl esters: *Dichloromaleïn Anil Dimethyl Ester*, m.p. 110°; whilst with aniline it yields *Dichloromaleïn Dianil*, m.p. 187° (A. **295**, 27):

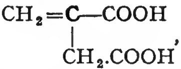


Dibromomaleïc Acid, $C_2Br_2(CO_2H)_2$, m.p. 120–125°, is obtained by acting on succinic acid with Br (C. 1900, I. 404), or by the oxidation of mucobromic acid with bromine water, silver oxide or nitric acid. It is very readily soluble, and readily forms the *anhydride*, $C_2Br_2(CO)_2O$, m.p. 115° (B. **13,** 736). *Chlorobromomaleïc Acid,* see B. **29,** R. 186.

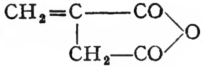
Dibromofumaric Acid, m.p. 219–222°, and *di-iodofumaric acid,* decomposes at 192°, are addition products of bromine and iodine with acetylene dicarboxylic acid (B. **12,** 2213; **24,** 4118). *Chloriodofumaric Acid,* m.p. 227° with decomposition, unites with chlorine to form an *iodosochloride* (1) (comp. p. 135). It reacts with alcohol, losing CO_2 and forms chloracrylic acid iodosochloride (2); which, with hot water, yields *iodosochloracrylic acid* (3); and finally this, with glacial acetic acid to form iodosochloracrylic acid acetate (4) (B. **38,** 2842):



Acids, $C_5H_6O_4 = C_3H_4(CO_2H)_2$.—Eight dicarboxylic acids, having this formula, are known. There are four unsaturated acids isomeric with ethylidene malonic acid described on p. 508: (1) *Itaconic acid,* (2) *Citraconic acid,* (3) *Mesaconic acid,* (4) *Glutaconic acid,* and three trimethylene dicarboxylic acids. Mesaconic and citraconic acids bear the same relation to each other as fumaric to maleïc acid. They show similar conversions of one into the other, which, however, occur less readily than in the case of the latter acids (B. **27,** R. 412). The introduction of the methyl group very considerably increases the tendency of citraconic acid to break down into its anhydride and water. This takes place at 100° under diminished pressure (comp. Chloral Hydrate). Mesaconic acid is more easily changed by acetyl chloride to citraconic anhydride than fumaric acid to maleïc anhydride. Furthermore, maleïc anhydride combines more readily, and therefore more rapidly, with water than citraconic anhydride.

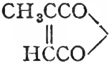
Itaconic Acid, *Methylene Succinic Acid,*

$$\begin{array}{l} CH_2{=}C{-}COOH \\ \quad\;\; | \\ \quad\;\; CH_2.COOH \end{array}$$
, m.p. 161°, is produced from its anhydride by combination with water; or by heating citraconic anhydride with 3 to 4 parts of water at 150°, whereby the citraconic anhydride is first transformed into itaconic anhydride which is then converted into the acid. It is not volatile in steam. Hydrogen converts it into pyrotartaric acid, and permanganate into hydroxyparaconic acid (*q.v.*) (A. **305,** 41). When electrolyzed it is decomposed into sym.-allylene or allene, $CH_2{=}C{=}CH_2$ (p. 90). When boiled with aniline it forms *pseudoitaconanilic acid,* the lactam of γ-anilinopyro-tartaric acid (p. 556) (A. **254,** 129). On the addition of HBr and Br_2, see pp. 500, 501.

Itaconic Dimethyl Ester, m.p. 38°, b.p.$_{11}$ 108°, when not quite pure, polymerises into a *glassy variety* possessing a strong refractive index (B. **14,** 2787; **A. 248,** 203; B. **38,** 691). *Itaconic Mono-esters* (B. **30,** 2649).

Itaconic Anhydride,  $\begin{array}{l}CH_2{=}C\text{——}CO\\ \quad|\\ \quad CH_2\text{—}CO\end{array}\!\!>O$, m.p. 68°, b.p.$_{30}$ 146°. Its name is formed by interchanging the syllables of aconitic acid. Itaconic anhydride is obtained from the hydrate (B. **13**, 1539), and from the silver salt by means of acetyl chloride (B. **13**, 1844). It has been found in the distillate obtained when citric acid is heated (B. **13**, 1542), and is probably produced by the decomposition of the aconitic acid which is first formed. It crystallizes from chloroform. When distilled at ordinary pressures it passes into citraconic anhydride, which unites with water far less readily than itaconic anhydride.

Itaconanilic Acid, m.p. 151·5 (A. **254**, 140).

Citraconic Acid, *Methyl Maleïc Acid,* m.p. 91°, is formed when its anhydride takes up water. The acid itself is soluble in water. Its volatility in steam is due to its decomposition below 100° into water and the anhydride which volatilises. It resembles mesaconic acid in its behaviour towards $KMnO_4$ (below).

Citraconic Anhydride,  $\begin{array}{l}CH_3CCO\\ \quad\|\\ HCCO\end{array}\!\!>O$ m.p. 7°, b.p. 213°, is found among the distillation products of *citric acid,* probably through the transformation of the first-formed itaconic anhydride. It is formed when citraconic acid or mesaconic acid is heated alone; and when treated with acetyl chloride. Prolonged heating at about 200° changes it partly into *Xeronic Acid* or diethyl maleïc anhydride (p. 519). *Bromocitraconic Anhydride,* m.p. 99° (B. **27**, 1855).

Hydrogen converts citraconic and mesaconic acids (below) into pyrotartaric acid. Addition products with halogens and halogen acids have been examined already as substitution products of pyrotartaric acid (pp. 500, 501). Either acid, when electrolyzed, yields *allylene,* $CH_3C{\equiv}CH$ (p. 90).

Citraconanilic Acid, m.p. 153° (A. **254**, 135).

Citraconanil, m.p. 98° (B. **23**, 2979; **24**, 314).

Mesaconic Acid, *Methyl Fumaric Acid, Hydroxytetrinic Acid,* $C_3H_4(CO_2H)_2$, m.p. 202°, is formed when citraconic or itaconic acid is heated with a small quantity of water at 200°; by the action of sunlight on an ether-chloroform solution of citraconic acid, containing a trace of bromine; by heating citraconic acid with dilute nitric acid, concentrated halogen acids, or concentrated sodium hydroxide solution (A. **269**, 182; B. **27**, R. 412) (comp. α- and β-Methyl Malic Acid, pp. 556, 557); and from dibromomethyl acetoacetic acid (p. 420). It is soluble with difficulty in water, and is non-volatile in steam. $KMnO_4$ oxidizes it to pyroracemic and oxalic acids (A. **305**, 407); *barium salt,* $C_5H_4O_4Ba+4H_2O$; *dimethyl ester,* b.p. 203°; *diethyl ester,* b.p. 229°.

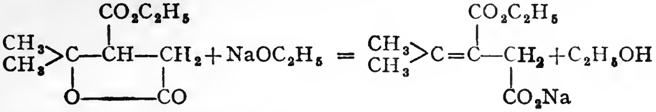
The relation between the results of partial hydrolysis and of esterification of the mesaconic acids have been investigated in detail. Hydrolysis of the di-alkyl ester yields α-*Mesaconic Monomethyl Ester,* m.p. 84°, and *mono-ethyl ester,* m.p. 68°, $HOCO\text{-}CH:C(CH_3)COOR$; whilst partial esterification yields a mixture of α-mesaconic acid esters and β-*Mesaconic Monomethyl Ester,* m.p. 52°, and *mono-ethyl ester,* m.p. 67°, $HOCO.C(CH_3):CHCOOR$. The structure of the latter bodies is demonstrated by their being prepared in a state of purity when γ-dibromo-α-methyl acetoacetic ester (p. 420) is boiled with water and barium carbonate. The α- acid esters are weaker acids than the β-compounds in which the free carboxyl group is united to a quarternary carbon atom; in the dialkyl esters this group is more difficult to hydrolyze. The acid-esters give rise to a corresponding series of *mono-ester acid chlorides, amides, anilides,* etc.

Mesaconyl Chloride, $ClOC.C(CH_3):CHCOCl$, b.p.$_{14}$ 65°, reacts with two molecules of aniline and forms α-*mesaconanilide acid chloride,* $ClOC.C(CH_3):CHCONH\text{-}C_6H_5$ (A. **353**, 139).

Bromomesaconic Acid, m.p. 220° (B. **27**, 1851, 2130).

The **Homologues of Itaconic, Citraconic, Mesaconic and Aticonic Acids** have become known mainly by the painstaking investigations of *R. Fittig* and his co-workers (A. **304**, 117; **305**, 1); they will be described before the glutaconic acids which are homologous with the above-named acids.

The parent substances from which these acids are formed are the alkyl paraconic acids (p. 557), which are prepared by condensation of aldehydes with succinic acid or pyrotartaric acid by means of acetic anhydride. On distillation they yield unsaturated monobasic acids, and anhydrides of two acids of the itaconic and citraconic series isomeric with the particular paraconic acid employed. If the alkyl paraconic esters are warmed with sodium alcoholate in alcoholic solution they are converted into the sodium salts of the corresponding itaconic mono-esters, from which the acids themselves are obtained by hydrolysis (A. **255**, 56; **256**, 50). Thus, terebic acid and sodium ethoxide produce teraconic acid; and similarly γ-dimethyl paraconic acid yields γ-dimethyl itaconic acid:



Alkyl itaconic acids when heated alone are converted into the anhydrides of alkyl citraconic acids. Alkyl citraconic acids become changed into alkyl itaconic acids when heated with water at 130–150°. This depends on the decomposition of the alkyl citraconic acids into anhydride and water below its boiling point, and the gradual transformation of this anhydride at a somewhat higher temperature into itaconic anhydride, which takes up water to form the stable acid.

The alkyl citraconic acids are easily converted into the corresponding alkyl mesaconic acids by the action of sunlight on an ether-chloroform solution of the acids to which a little bromine had been added.

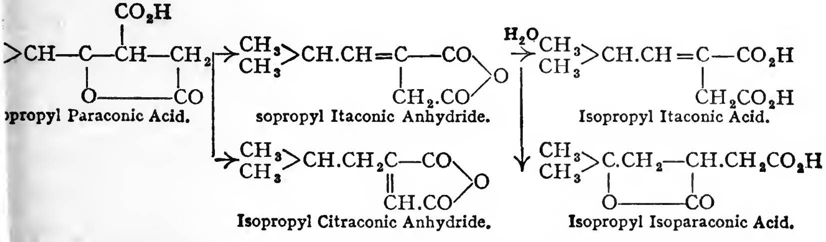
When the alkyl itaconic acids are boiled with sodium hydroxide solution, the position of the double bond becomes changed, and there are produced alkyl mesaconic acids and a new series of isomeric acids named by *Fittig*, *alkyl aticonic acids*. The reaction is, however, not a general one, since γ-methyl itaconic acid is stable towards boiling sodium hydroxide solution, whilst γ-dimethyl itaconic acid readily yields the aticonic acid (A. **330**, 292). The alkyl aticonic acids when boiled with sodium hydroxide solution pass mainly into the alkyl itaconic acids, so that ultimately a point of equilibrium is reached which is not changed by further boiling.

A mixture of alkyl itaconic and alkyl aticonic acids (or alkylidene pyrotartaric acids) also result from the condensation of ketones, such as acetone and alkyl methyl ketone, with succinic acid ester by means of sodium methoxide (*Stobbe*, B. **30**, 94; A. **321**, 83).

Aromatic itaconic and aticonic acids can be prepared by the two nucleus-synthetic methods (Vol. II.).

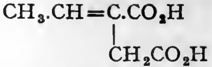
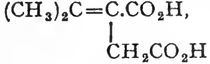
The alkyl itaconic and alkyl mesaconic acids are as little volatile in steam as he itaconic and mesaconic acids themselves, whilst of the alkyl citraconic acids, ome are only obtained as anhydrides, and others are dissociated into the anhydride and water below 100°, like citraconic acid; these anhydrides are volatile in steam. The calcium and barium salts of the alkyl mesaconic acids are readily soluble in water, whilst the corresponding alkyl itaconic acid salts dissolve with difficulty.

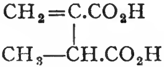
The itaconic acids are converted into the paraconic acids, from which they were prepared, by heating with hydrochloric or hydrobromic acids and by suitable treatment with sulphuric acid. The isopropyl itaconic acid alone behaves xceptionally, by yielding *isopropyl isoparaconic acid*, isomeric with the original opropyl paraconic acid:

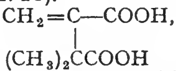


Reduction with sodium amalgam converts the alkyl itaconic, alkyl citraconic, nd alkyl mesaconic acids into the corresponding succinic acids, the first acid eacting least readily than the third, and the second most easily of all three.

Homologous Itaconic Acids.

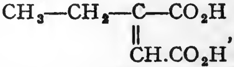
γ-Methyl Itaconic Acid, Ethylidene Succinic Acid,  $\begin{array}{l}CH_3.CH{=}C.CO_2H\\ \qquad\quad|\\ \qquad\quad CH_2CO_2H\end{array}$ m.p. 165°. *γ-Ethyl Itaconic Acid,* m.p. 162°. *γ-*n*-Propyl Itaconic Acid,* m.p. 159°. *γ-Isopropyl Itaconic Acid,* m.p. 189°. *γ-Isobutyl Itaconic Acid,* m.p. 160°. *γ-*n.*-Hexyl Itaconic Acid,* m.p. 129°. *Teraconic Acid, γ-Dimethyl Itaconic Acid,*  $\begin{array}{l}(CH_3)_2C{=}C.CO_2H,\\ \qquad\quad|\\ \qquad\quad CH_2CO_2H\end{array}$ m.p. 162°, is prepared from terebic acid (p. 517, and Vol. II.); and by the condensation of succinic ester and acetone by means of sodium ethoxide (B. **36,** 197; J. pr. Ch. [2] **67,** 197). Hydrobromic or sulphuric acid reconverts it into terebic acid; water at 190° decomposes it into CO_2 and isocaprolactone (C. 1889, I. 780); *anhydride,* b.p. 275°. *γ-Methyl Ethyl Itaconic acid,* m.p. 181° with decomposition.

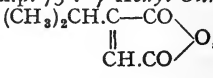
α-Methyl Itaconic Acid,  $\begin{array}{l}\quad CH_2{=}C.CO_2H\\ \qquad\quad|\\ CH_3{-}CH.CO_2H\end{array}$ m.p. 150°, is obtained from pyrocinchonic acid (below); *anhydride,* m.p. 63°, is produced by heating anhydromethyl aconitic acid (C. 1906, II. 21).

αα-Dimethyl Itaconic Acid,  $\begin{array}{l}CH_2{=}C{-}COOH,\\ \qquad|\\ (CH_3)_2CCOOH\end{array}$ m.p. 141°, is prepared from α-bromotrimethyl succinic acid and diethyl aniline; *anhydride,* b.p. 210–215°; *diethyl ester,* b.p.$_{20}$ 127° (C. 1902, I. 180; 1904, I. 434).

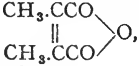
αγ-Dimethyl Itaconic Acid, $CH_3CH : C(COOH).CH(CH_3)COOH$, m.p. 202° (*anhydride,* b.p.$_{26}$ 131°) and *α-Ethyl Itaconic Acid,* $CH_2 : C(COOH).CH(C_2H_5)COOH$ (*anhydride,* m.p. 52), result from boiling methyl ethyl maleïc acid (p. 519) with sodium hydroxide solution; the former also, from αγ-dimethyl paraconic acid by boiling it with $NaOC_2H_5$ solution (B. **39,** 1535). The alkyl itaconic acids mostly have no sharp melting points, owing to their tendency to form anhydrides.

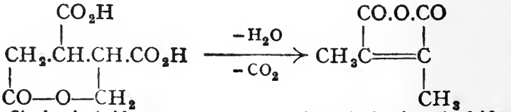
Homologous Citraconic Acids, *Alkyl Maleïc Acids.*

γ-Methyl Citraconic Acid, Ethyl Maleïc Acid,  $\begin{array}{l}CH_3{-}CH_2{-}C{-}CO_2H\\ \qquad\qquad\ \|\\ \qquad\qquad CH.CO_2H\end{array}$, m.p. 100°, can also be obtained by heating β-ethyl malic acid (B. **37,** 2382; **38,** 2737); *anhydride,* b.p. 229°, is obtained from ethyl fumaric acid, p. 519) by heating it with acetyl chloride. When vapourised with ammonium it forms the *imide,* m.p. 141°. *γ-Ethyl Citraconic Acid,* n*-Propyl Maleïc Acid,* m.p. 94°; *anhydride,* b.p. 224°. *γ-Propyl Citraconic Acid,* m.p. 80°. *γ-Isopropyl Citraconic Acid,* m.p. 78°. *γ-Isobutyl Citraconic Acid,* m.p. 75°. *γ-Hexyl Citraconic Acid,* m.p. 86°.

γ-Dimethyl Citraconic Anhydride,  $\begin{array}{l}(CH_3)_2CH.C{-}CO\\ \qquad\qquad\|\qquad\ \ >O\\ \qquad\qquad CH.CO\end{array}$, m.p. 5°, b.p.$_{61}$ 138° (C. 1899, I. 668, 780).

The γ-alkyl citraconic acids or monoalkyl maleïc acids do not melt sharply on account of the formation of anhydrides. The α-alkyl citraconic or dialkyl maleïc acids only exist as anhydrides, which are formed when the acid is liberated from its salts by stronger acids.

Pyrocinchonic Anhydride, *Dimethyl Maleïc Anhydride, α-Methyl Citraconic Anhydride,*  $\begin{array}{l}CH_3.CCO\\ \quad\ \ \|\qquad >O\\ CH_3.CCO\end{array}$, m.p. 96°, b.p. 223°, is formed when cinchonic acid (*q.v.*) is heated:



Cinchonic Acid. Pyrocinchonic Anhydride.

It also results, together with terebic acid, when turpentine oil is oxidized with nitric acid; from α-dichloro- and α-dibromo-propionic acid and silver (B. **18,** 826, 835); by condensation of pyroracemic acid and sodium succinate by means of acetic anhydride (A. **304**, 158); by distillation of αβ-dimethyl malic acid (p. 556) under reduced pressure (a method of preparation); by distillation of anhydromethyl aconitic acid (C. 1906, II. 21).

Dimethyl ester, b.p. 219°, and *diethyl ester*, b.p. 237°, are prepared from silver pyrocinchonate and iodo-alkyls (B. **33**, 1410). The solution of pyrocinchonic anhydride reacts strongly acid and decomposes alkali salts forming pyrocinchonates, the constitution of which has already (p. 513) been discussed. Ferric chloride produces a dark red coloration in pyrocinchonic anhydride solutions. Reduction produces two dimethyl succinic acids (p. 494). It unites with chlorine to form dimethyl dichlorosuccinic anhydride (B. **26**, R. 190). When boiled with 20 per cent. sodium hydroxide solution, pyrocinchonic acid is converted into dimethyl fumaric acid and β-methyl itaconic acid (A. **304**, 156). Pyrocinchonic ester, when heated with alcoholic ammonia, yields amino-dimethyl-succinimide (p. 557) and *pyrocinchonimide*, m.p. 119° (B. **33**, 1408), which, on hydrolysis yields, in part, β-methyl itaconic acid.

Methyl Ethyl Maleïc Anhydride, b.p. 236°, is formed by condensation of pyrotartaric acid and pyroracemic acid, by means of acetic anhydride (A. **267**, 214); by distillation of αγ-dimethyl paraconic acid whereby α-methyl βγ-pentinic acid is also formed (B. **39**, 1535); by the slow distillation of methyl ethyl malic acid; *imide*, m.p. 67°; *dimethyl ester*, b.p. 235°. The *imide* and *anhydride* can also be obtained from the destruction of hæmatin or hæmatinic acid (comp. hæmoglobin) (A. **345**, 1).

Methyl Propyl Maleïc Anhydride, b.p. 242° (*imide*, m.p. 57°) and *Methyl Isopropyl Maleïc Anhydride*, b.p. 241° (*imide*, m.p. 45°) are obtained from methyl propyl and methyl isopropyl malic acid (A. **346**, 1).

Xeronic Anhydride, Diethyl Maleïc Anhydride, b.p. 242°, is prepared by heating citraconic anhydride (A. **346**, 1).

Homologous Mesaconic Acids, *Alkyl Fumaric Acids.* For the formation of alkyl mesaconic acids from the corresponding alkyl itaconic and alkyl citraconic acids, see p. 517.

The products of reaction of alcoholic potassium hydroxide and the γ-dibromoderivatives of monoalkyl acetoacetic ester belong to the alkyl fumaric acid series (C. 1899, I. 780); hydroxytetrinic acid being mesaconic acid, and hydroxypentinic acid being ethyl fumaric acid, etc. (p. 420).

The reaction is most simply explained by the assumption that keto- or hydroxyaldehydic acids are first formed, which are then converted into unsaturated carboxylic acids (B. **32**, 1005):

$$X_2CH.COCHR'.CO_2R \longrightarrow OCH.CO.CHR'.CO_2R$$

$$\longleftarrow$$

$$O.CH.C(OH){=}CR'.CO_2R \longrightarrow CO_2H.CH : CR'.CO_2R.$$

Also, monoalkyl fumaric acids are obtained from monoalkyl ethane tricarboxylic acids by the introduction of halogen and subsequent splitting off of halogen acid and CO_2 (B. **24**, 2008).

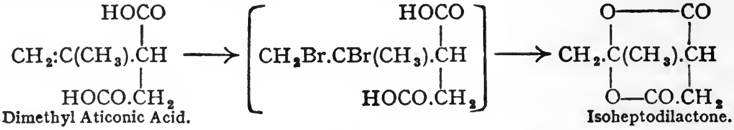
Ethyl Fumaric Acid, γ-Methyl Mesaconic Acid, m.p. 194°. n.-*Propyl Fumaric Acid, γ-Ethyl Mesaconic Acid*, m.p. 174°. *Isopropyl Fumaric Acid, γ-Dimethyl Mesaconic Acid*, m.p. 184°. n.-*Butyl Fumaric Acid, γ-Propyl Mesaconic Acid*, m.p. 170°. *γ-Isopropyl Mesaconic Acid*, m.p. 185°. *γ-Isobutyl Mesaconic Acid*, m.p. 205°. *γ-Hexyl Mesaconic Acid*, m.p. 153°.

Dimethyl Fumaric Acid, α-Methyl Mesaconic Acid, m.p. 239°; *diethyl ester*, b.p. 235°, is formed when diazopropionic ester is heated (p. 410) (B. **37**, 1272).

Aticonic Acids.—For the formation of these acids from the alkyl itaconic acids by synthetic methods, see p. 517. *Dimethyl Aticonic Acid, 1-Methyl Vinyl Succinic Acid, γ-Methyl Methylene Pyrotartaric Acid*, $\begin{matrix}CH_3\\CH_2\end{matrix}\!\!>\!C.CH\!<\!\!\begin{matrix}CH_2CO_2H\\CO_2H\end{matrix}$, m.p. 146°, results when teraconic acid is boiled with sodium hydroxide solution. *Isobutyl Aticonic Acid, 2-Isopropyl Vinyl Succinic Acid*, $\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!CH.CH{=}CH.CH\!<\!\!\begin{matrix}CH_2CO_2H\\CO_2H\end{matrix}$, m.p. 93°. *Hexyl Aticonic Acid, 2-Amyl Vinyl Succinic Acid,*

$CH_3[CH_2]_4CH{=}CH.CH{<}\begin{smallmatrix}CH_2CO_2H\\ CO_2H\end{smallmatrix}$, m.p. 78° (A. **304**, 117; **305**, 1). *Methyl Ethyl Aticonic Acid, γ-Ethylidene γ-Methyl Pyrotartaric Acid, 1,2-Dimethyl Vinyl Succinic Acid,* $(CH_3)CH{:}C(CH_3)CH{<}\begin{smallmatrix}CH_2CO_2H\\ CO_2H\end{smallmatrix}$, m.p. 142°, is the chief product of reaction between methyl ethyl ketone and sodium ethoxide on succinic ester. Oxidation converts it into acetic acid and lævulinic acid (A. **321**, 106).

In indifferent solvents, the alkyl aticonic acids readily take up bromine. The dibromides, on losing HBr, change into the bromolactonic acids, which are converted by hydrogen into isoparaconic acids, and by boiling water, or when standing in alcoholic solution, into the neutral dilactones:



Dimethyl Aticonic Acid. Isoheptodilactone.

The formation of dilactones requires that each of the two doubly bound carbon atoms shall stand in the γ-position to one of the two carbonyl groups (A. **304**, 135). This shows the alkyl aticonic acids to be γδ-unsaturated acids. It follows, therefore, that one of the itaconic acids is theoretically not possible, since this acid lacks the δ carbon atom. The aticonic acids can be looked on as being vinyl succinic acids, or can be derived from pyrotartaric acid, considerations which are indicated in the names given to the dimethyl aticonic acids.

The dilactones, obtained from the aticonic acids through the bromolactonic acids, are converted by prolonged boiling in water into isomeric unsaturated lactonic acids, known as *isaconic acids*. Sodium amalgam converts them into isoparaconic acids, in the same way that the better known aconic acids give paraconic acids.

Glutaconic Acid, $CO_2H.CH:CH.CH_2.CO_2H$, m.p. 132°, is prepared from dicarboxylic glutaconic ester by hydrolysis with hydrochloric acid (A. **222**, 249); from coumalic ester and barium hydroxide (A. **264**, 301); from β-hydroxyglutaric acid (p. 559), and sodium hydroxide solution (B. **33**, 1452). It is isomeric with itaconic, citraconic, mesaconic and ethylidene malonic acids.

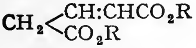
The *zinc salt* is deposited from its boiling solution; *ethyl ester*, b.p. 237°, is most readily obtained by distillation of β-acetoxyglutaric ester (p. 599). Under certain conditions it polymerises to a di-molecular substance which, on hydrolysis, yields *diglutaconic acid* $[C_3H_4(CO_2H)_2]_2$, m.p. 207°. This acid is also formed by hydrolysing the dimolecular isaconitic ester (*q.v.*), whilst the di-molecular glutaconic dicarboxylic ester (*q.v.*) yields a diglutaconic acid, m.p. 234° (B. **34**, 675). When warmed with sodium ethoxide two molecules of glutaconic ester unite with the loss of alcohol, and there is formed *dicarboxycyclohexenone acetic ester* (B. **37**, 2113, comp. C. 1903, I. 960).

Glutaconic Anhydride, m.p. 82°, is formed when glutaconic and β-hydroxyglutaconic acids are heated (*Kekulé*); and from glutaconic acid and acetyl chloride (m.p. 87°, B. **27**, 882); the *imide, αα-Dioxypyridine,* $CH{\lessdot}\begin{smallmatrix}CH.CO—\\ CH_2—CO\end{smallmatrix}{>}NH$ or $CH{\lessdot}\begin{smallmatrix}CH—C(OH)\\ CH{=}C(OH)\end{smallmatrix}{\gtrdot}N$, m.p. 183°, is formed (1) from glutaconaminic acid; (2) from glutaconamide, and (3) from β-hydroxyglutaric amide, when these are heated with H_2SO_4 to 130–140°. Na and CH_3I react with it to produce glutaconic methylimide; with nitrous acid it gives rise to a nitroso-compound; when distilled over zinc dust pyridine is formed: PCl_5 produces *pentachloropyridine,* C_5Cl_5N (see Constitution of Pyridine, Vol. II.).

β-Chloroglutaconic Acid, m.p. 129°, is prepared from acetone dicarboxylic acid and PCl_5 (p. 566; comp. glutinic acid, p. 523). *Tetrachloroglutaconic Acid,* m.p. 109–110° (B. **26**, 2697).

Homologous Glutaconic Acids. The alkylated glutaconic acids are best obtained by heating the acetyl compounds of the alkylated β-hydroxyglutaric acids, just as glutaconic acid itself from alkylated glutaconic acids (comp. C. 1903, II. 1313).

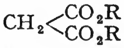
The CH_2- group of the glutaconic ester is replaceable by alkyl groups by means of sodium or sodium alcoholate and iodoalkyls. It appears, therefore that the second carboxyl group exerts its influence on the methylene group across the ethylene group;



$$CH_2<\begin{matrix}CH{:}CHCO_2R\\CO_2R\end{matrix}$$

Glutaconic Ester.

and



$$CH_2<\begin{matrix}CO_2R\\CO_2R\end{matrix}$$

Malonic Ester.

The reaction with C_2H_5ONa and CH_3I not only converts glutaconic ester into $\alpha\alpha$-dimethyl glutaconic ester, but also produces $\alpha\gamma$-dimethyl glutaconic ester. Of this latter compound two desmotropic forms, I. and II. (see below) exist; further methylating of II. results in the production of $\alpha\alpha\gamma$-trimethyl glutaconic ester (C. 1903, I. 1405):

I. $RO_2C.CH(CH_3){-}CH{=}CHCO_2R$ and II. $RO_2C.C(CH_3){=}CH{-}CH_2CO_2R$

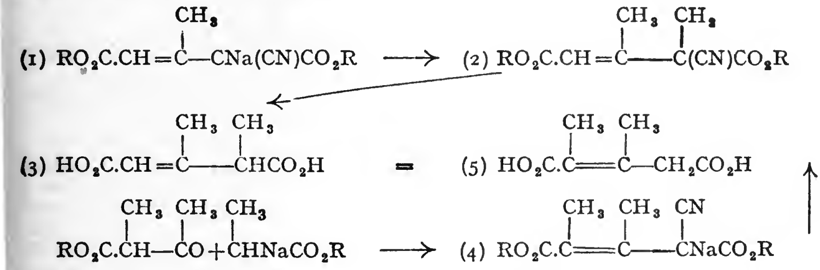
$\downarrow$ $\downarrow$

$RO_2C.C(CH_3)_2{-}CH{=}CHCO_2R$ $RO_2C.C(CH_3){=}CH{-}CH(CH_3)CO_2R$

$\downarrow$

$RO_2C.C(CH_3){=}CH{-}C(CH_3)_2CO_2R$

The existence of the two desmotropic modifications $HO_2C.CR{=}CH{-}CH_2CO_2H$ and $HO_2C.CHR{-}CH{=}CHCO_2H$ is also demonstrated by the identity of the $\alpha\beta$- and $\beta\gamma$-dialkyl glutaconic acids, obtained by the following syntheses: sodium cyanacetic ester and acetoacetic ester produce sodium cyano-β-methyl-glutaconic ester (1); CH_3I converts this into α-cyano-$\alpha\beta$-dimethyl glutaconic ester (2), which by hydrolysis and loss of CO_2 is changed into $\alpha\beta$-dimethyl-glutaconic acid (3). This substance is identical with the decomposition product of the condensation of cyanacetic ester and α-methyl acetoacetic ester (4), which should be similar to $\beta\gamma$-dimethyl glutaconic acid (5) (C. 1906, I. 183):



$$(1)\ RO_2C.CH{=}\overset{CH_3}{C}{-}CNa(CN)CO_2R \longrightarrow (2)\ RO_2C.CH{=}\overset{CH_3}{C}{-}\overset{CH_3}{C}(CN)CO_2R$$

$$(3)\ HO_2C.CH{=}\overset{CH_3}{C}{-}\overset{CH_3}{C}HCO_2H = (5)\ HO_2C.\overset{CH_3}{C}{=}\overset{CH_3}{C}{-}CH_2CO_2H$$

$$RO_2C.\overset{CH_3}{C}H{-}\overset{CH_3}{C}O+\overset{CH_3}{C}HNaCO_2R \longrightarrow (4)\ RO_2C.\overset{CH_3}{C}{=}\overset{CH_3}{C}{-}\overset{CN}{C}NaCO_2R$$

The alkyl glutaconic acids show *cis-trans* isomerism.

β-Methyl Glutaconic Acid, Homomesaconic acid, $HO_2C.CH : C(CH_3).CH_2CO_2H$. *Cis*-form 147°, *trans*-form, 116°, is prepared from cyano-β-methyl-glutaconic ester (see below); from carboxyl β-methyl glutaconic ester $CO_2R)_2CH.C(CH_3)$:-$CHCO_2R$; and from isodehydracetic acid (*lactone* of *aci-acetyl β-glutaconic mono-ester,* $CH_3C(OH) : (CO_2R).C(CH_3) : CHCO_2H$) obtained by splitting the *cis*- and *trans*-forms. The *cis*-acid can be transformed into the *trans*-acid by boiling with strong alkali. The *cis*-acid forms an *anhydride,* m.p. 86°; *imide,* m.p. 194° (A. **345,** 60).

$\alpha\beta$- or $\beta\gamma$-Dimethyl Glutaconic Acid (see above), m.p. 148°, is formed by the method (3), above; also from β-methyl glutaconic ester by the action of sodium and iodomethane (A. **345,** 117); *anhydride,* b.p.$_{25}$ 162°; *imide,* m.p. 189°.

$\alpha\alpha$-Dimethyl Glutaconic Acid, $HO_2C.C(CH_3)_2CH : CHCO_2H$, *cis*-form, m.p. 134°; *trans*-form, m.p. 172°, is prepared from α-dimethyl glutolactonic acid (B. **33,** 1920); from β-hydroxy α-dimethyl glutaric acid; from glutaconic ester, sodium and iodomethane; some *$\alpha\gamma$-Dimethyl Glutaconic Acid,* m.p. 147°, is also formed (above) (C. 1903, II. 1315).

$\alpha\alpha\gamma$-Trimethyl Glutaconic Acid, cis-form, m.p. 125°, *trans*-form, m.p. 150°, is formed from β-hydroxy trimethyl glutaric acid and by methylating $\alpha\gamma$-dimethyl glutaric acid. The *cis*- acid gives rise to an *anhydride,* m.p. 88°.

$\alpha\alpha\beta$-Trimethyl Glutaconic Acid, cis-form, m.p. 133°, *trans*-form, m.p. 148°

(C. 1903, II. 1315). *αβγ-Trimethyl Glutaconic Acid,* m.p. 127°; ***anhydride,*** m.p. 119°; *imide,* m.p. 180° (C. 1906, I. 185).

Hydromuconic Acids.

αβ-acid: $CO_2H.CH_2CH_2CH{=}CHCO_2H$, m.p. 169°, stable form.
βγ-acid: $CO_2H.CH_2CH{=}CH.CH_2CO_2H$, m.p. 195°, labile form.

The *labile* acid is formed by the reduction of dichloromuconic acid or muconic acid (below), and of diacetylene carboxylic acid (p. 523). It dissolves with difficulty in cold water, and is oxidised to malonic acid by potassium permanganate. When boiled with sodium hydroxide solution it is transformed into the *stable* acid, which is oxidised to succinic acid by permanganate. Sodium amalgam converts the labile acid into the stable form and reduces this to adipic acid (p. 505). *Dichlorides* and *Dimethylene ester* (C. 1901, II. 1119).

α-Methylene Glutaric Acid, $CH_2:C(COOH)CH_2.CH_2CO_2.H$, m.p. 129–130°, and *α-Ethylidene β-Methyl Glutaric Acid,* $CH_3.CH:C(CO_2H)CH(CH_3)CH_2CO_2H$, m.p. 129°. The esters of these acids are obtained by the polymerisation of acrylic and crotonic acids respectively (pp. 294, 295) by means of sodium alcoholate (B. **33,** 3766; **34,** 427). α-Methylene glutaric acid is also formed by the distillation of α-methyl α-hydroxyvaleric acid (B. **36,** 1202). Suitable methods of reduction convert these acids into α-methyl glutaric acid and α-ethyl β-methyl glutaric acids respectively.

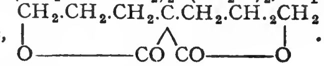
α-Ethylidene Glutaric Acid, $CH_3CH:C(COOH)CH_2CH_2CO_2H$, m.p. 152°, see δ-Caprolactone Carboxylic Acid (p. 560). Sodium hydroxide solution converts it into *α-Vinyl Glutaric acid,* $CH_2:CH.CH(CO_2H)CH_2CH_2CO_2H$, m.p. 97° (B. **31,** 2000).

Isoamylidene Glutaric Acid, $(CH_3)_2CHCH_2CH:C(CO_2H)CH_2CH_2CO_2H$, m.p. 15°, is formed together with diisovalerylidene glutaric acid (see below).

Allyl Succinic Acid, $CH_2:CH.CH_2CH(CO_2H)CH_2CO_2H$, m.p. 94°, is prepared from allyl ethylene tricarboxylic ester (B. **16,** 333). *Allyl Methyl-* and *Allyl-Ethyl Succinic Acid,* see B. **25,** 488.

C. Diolefine Dicarboxylic Acids.

Diallyl Malonic Acid, $(CH_2{=}CHCH_2)_2C(CO_2H)_2$, m.p. 133°, with hydrobromic acid yields a dilactone,



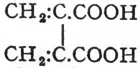
$$\begin{array}{l}CH_2.CH_2.CH_2.C.CH_2.CH.{}_2CH_2\\ |\qquad\qquad\qquad\ \wedge\qquad\qquad\ |\\ O\text{———}CO\ CO\text{———}O\end{array}$$

. It breaks down into CO_2 and diallyl acetic acid when heated (p. 306).

Muconic Acid, $CO_2H.CH{=}CH{-}CH{=}CH.CO_2H$, m.p. 292°, with decomposition, is formed when alcoholic potassium hydroxide acts on the dibromide of βγ-hydromuconic acid; also, synthetically, from glyoxal and two molecules of malonic acid by means of pyridine; *dimethyl ester,* m.p. 158° (B. **35,** 1147). *Dichloromuconic Acid,* $C_6H_4Cl_2O_4$, results when PCl_5 acts on mucic acid (B. **24,** R. 629). It yields βγ-hydromuconic acid with sodium amalgam (B. **23,** R. 232). *Dichloromuconic Acid Dichloride,* and *Dimethyl Ester* (C. 1901, II. 1119).

Isomeric muconic acids are not known.

Dimethylene Succinic Acid,



$$\begin{array}{l}CH_2{:}C.COOH\\ \quad\ |\\ CH_2{:}C.COOH\end{array}$$

may be considered as being the parent substance of a large number of strongly coloured well-crystallising acids of the aromatic series (Vol. II.). It easily passes into a more deeply coloured anhydride, and exhibits a reversible difference of state in violet and ultra-violet light (p. 63). Therefore *Stobbe* named the hypothetical acid *Fulgenic Acid* (fulgere = to shine) and the anhydride *fulgide.* The lesser known aliphatic fulgenic acids and fulgides are colourless (A. **359,** 1, etc.).

Diisopropylidene Succinic Acid, ααδδ-Tetramethyl Fulgenic Acid, $(CH_3)_2C:-C(COOH).C(COOH):C(CH_3)_2$, m.p. 230° with decomposition, and *Isopropylidene Isobutylidene Succinic Acid, ααδ-Dimethyl Isopropyl Fulgenic Acid,* $(CH_3)_2C:-C(COOH)C(COOH):CHCH(CH_3)_2$, m.p. 226° with decomposition, result from the reaction of teraconic ester and acetone or isobutyl aldehyde respectively, with sodium ethoxide. The *anhydrides,* m.ps. 59° and 72°, are formed by means of acetyl chloride (B. **38,** 3673, 3683).

Diisovaleral Glutaric Acid, $CH_2[C(CO_2H):CHCH_2CH(CH_3)_2]_2$, m.p. 220°, and is obtained from glutaric acid and isovaleraldehyde with acetic anhydride and sodium ethoxide or sodium (A. **282,** 357).

D. Acetylene and Polyacetylene Dicarboxylic Acids.

Acetylene Dicarboxylic Acid, $CO_2H.C\equiv C.CO_2H+2H_2O$, m.p. 175° with decomposition, is obtained when aqueous or alcoholic potassium hydroxide acts on dibromo- and isodibromo-succinic acid (A. **272,** 127). It effloresces on exposure. The anhydrous acid crystallises from ether in thick plates. The acid unites with the halogen acids to form halogen fumaric acids, whilst with bromine and iodine it yields dihalogen fumaric acids (p. 515). Its esters unite with bromine and form dibromomaleïc esters and dibromofumaric esters (B. **25,** R. 855). With water they yield oxalacetic ester (B. **22,** 2929). They combine with phenylhydrazine and hydrazine, forming the same pyrazolone derivatives as oxalacetic ester (B. **26,** 1719); and with diazobenzene imide they form phenyltriazole dicarboxylic ester (B. **26,** R. 585). Oxalacetic ester and acetylene dicarboxylic ester are condensed by alcoholic potassium hydroxide to aconitic ester (B. **24,** 127). (See also Acetoxymaleïc Anhydride, p. 565.) The primary *potassium salt,* C_4O_4HK, is not very soluble in water, and when heated decomposes into CO_2 and potassium propiolate (p. 303); *silver salt* breaks down readily into CO_2 and silver acetylide (A. **272,** 139); *diethyl ester,* b.p.$_{15}$ 145–148°, is obtained from dibromosuccinic ester with sodium ethoxide (B. **26,** R. 706). (See also Thiophene Tetracarboxylic Esters.)

Glutinic Acid, $CO_2H.C\equiv C.CH_2.CO_2H$, m.p. 145° with evolution of carbon dioxide, is obtained by the action of alcoholic potassium hydroxide (B. **20,** 147) upon chloroglutaconic acid (p. 520).

Diacetylene Dicarboxylic Acid, $CO_2H.C\equiv C—C\equiv C.CO_2H+H_2O$, is made by the action of potassium ferricyanide on the copper compound of propiolic acid (B. **18,** 678, 2269). It assumes a dark red colour on exposure to light, and at 177° explodes with a loud report. Sodium amalgam reduces it to hydromuconic acid, and at the same time splits it up into adipic and propionic acids. The *ethyl ester,* b.p.$_{200}$ 184°. Zinc and hydrochloric acid decompose it and yield propargylic ester (p. 303).

Tetra-acetylene Dicarboxylic Acid, $CO_2H.C\equiv C.C\equiv C.C\equiv C.C\equiv C.CO_2H$. Carbon dioxide escapes on digesting the acid sodium salt of diacetylene dicarboxylic acid with water, and there is formed the sodium salt of *diacetylene monocarboxylic acid,* $CH\equiv C.C\equiv CO_2Na$, which cannot be obtained in a free condition. When potassium ferricyanide acts on the copper compound of this acid, tetra-acetylene dicarboxylic acid is formed. This crystallizes from ether in beautiful needles, rapidly darkening on exposure to light and exploding violently when heated. Consult B. **18,** 2277, for an experiment made to explain the explosibility of this derivative.

V. TRIHYDRIC ALCOHOLS: GLYCEROLS AND THEIR OXIDATION PRODUCTS

The trihydric alcohols, or glycerols, and their oxidation products are connected with the dihydric alcohols (glycols) and their oxidation products.

The glycerols, so-called after their most important member, are obtained from the hydrocarbons by the substitution of three hydroxyl groups for three hydrogen atoms, linked to different carbon atoms. As the number of hydroxyl groups increases, the number of theoretically possible classes of glycerols, in contrast to the glycols, also becomes greater. The number of possible classes of oxidation products also grows accordingly, and in the case of the trihydric alcohols this number is 19. However, this chapter of organic chemistry has been less regularly developed than that pertaining to the dihydric derivatives, and it may be said that the glycerols serve, even to a less degree than the glycols, as parent bodies for the preparation of the various classes belonging here, some of which are: *dihydroxymonocarboxylic acids, monohydroxydicarboxylic acids, diketone-monocarboxylic acids, tricarboxylic acids.*

Hydroxydialdehydes, hydroxydiketones, trialdehydes, aldehyde-diketones and triketones are represented to only a slight extent, if at all. The same may be said of the hydroxyaldehyde ketones, hydroxyaldehydic acids, hydroxyketonic acids, aldehyde-carboxylic acids, and aldehyde-ketone-carboxylic acids.

I. TRIHYDRIC ALCOHOLS

Glycerol stands at the head of this class, although it is not a triprimary alcohol, but rather a diprimary-secondary alcohol. The simplest imaginable triprimary alcohol would have the formula $CH(CH_2OH)_3$, and could be referred to trimethyl methane, $CH(CH_3)_3$, whereas glycerol is derived from propane, and considering the structure of the carbon nucleus, it is the simplest trihydric alcohol.

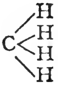
Although it may appear unnecessary to develop all the possible kinds of trihydric alcohols and their oxidation products, as was done with the glycols, yet the oxidation products theoretically possible from glycerol will be deduced. By enlarging this scheme we really construct a comparative review of the oxygen compounds, obtainable from methane, ethane, and propane.

It is also possible to tabulate the formulæ of the oxygen derivatives of a hydrocarbon in such manner that the hydrogen atoms may be regarded as replaced, step by step, by hydroxyl groups, and we may indicate the number of hydrogen atoms attached to one carbon atom, which have been replaced by hydroxyl groups.*

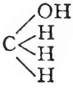
Thus, in compounds containing more than one hydroxyl attached to the same carbon atom, numbers are employed to express the formulæ of ortho-derivatives, usually only stable in the form of ethers. When a carbon atom of a hydrocarbon is joined to hydrogen, and no hydrogen atoms are replaced by hydroxyl, this is expressed by a zero:

Methane$=CH_4=0$

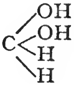
0



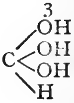
I
1



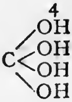
II
2



III
3



IV
4



Ethane$=CH_3.CH_3=00$

	I	II	III	IV	V	VI
00	10	20	30	22	32	33
CH_3 | CH_3	CH_2OH | CH_3	$CH(OH)_2$ | CH_3	$C(OH_3)$ | CH_3	$CH(OH)_2$ | $CH(OH)_2$	$C(OH)_3$ | $CH(OH)_2$	$C(OH)_3$ | $C(OH)_3$
		11	21	31		
		$CH_2.OH$ | $CH_2.OH$	$CH(OH)_2$ | CH_2OH	$C(OH)_3$ | CH_2OH		

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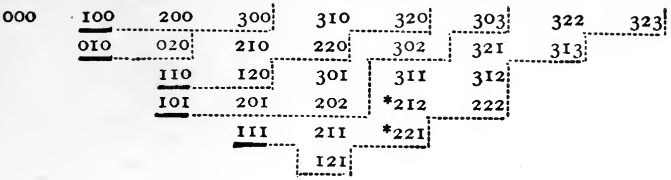
* The author is indebted to *A. J. Baeyer* in Munich for indicating this method of exposition, "which has the great advantage of facilitating the derivation of the possible hydroxyl compounds from the higher hydrocarbons, and also to make apparent the degree of oxidation, *i.e.* the number of oxygen valencies which have entered."

Propane $=CH_3.CH_2.CH_3=000$

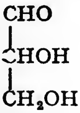


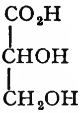
The following formulæ correspond with these groups of numbers:

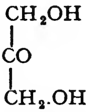
I:	000	$CH_3.CH_2.CH_3$	Propane
	100	$CH_2OH.CH_2.CH_3$	n-Propyl Alcohol
	010	$CH_3.CHOH.CH_3$	Isopropyl Alcohol
II:	200	$CH(OH)_2.CH_2.CH_3$	Propionic Aldehyde
	020	$CH_3C(OH)_2CH_3$	Acetone
	110	$CH_2OHCH.OH.CH_3$	Propylene Glycol
	101	$CH_2OH.CH_2.CH_2OH$	Trimethylene Glycol
III:	300	$C(OH)_3.CH_2.CH_3$	Propionic Acid
	210	$CH(OH)_2.CH(OH)CH_3$	Unknown (pp. 336, 340)
	201	$CH(OH)_2CH_2.CH_2OH$	β-Hydroxypropionic Aldehyde
	120	$CH_2OH.C(OH)_2CH_3$	Hydroxyacetone, Ketol
	111	$CH_2OH.CHOH.CH_2OH$	Glycerol
IV:	310	$C(OH)_3.CHOH.CH_3$	Lactic Acid
	301	$(COH)_3.CH_2.CH_2OH$	Hydracrylic Acid
	220	$CH(OH)_2.C(OH)_2.CH_3$	Pyroracemic Aldehyde
	202	$CH(OH)_2.CH_2.CH(OH)_2$	Malonic Dialdehyde (p. 347)
	211	$CH(OH)_2.CH.OH.CH_2OH$	Glycerose
	121	$CH_2OH.C(OH)_2.CH_2OH$	Dihydroxyacetone
V:	320	$C(OH)_3.C(OH)_2.CH_3$	Pyroracemic Acid
	302	$C(OH)_3.CH_2.CH(OH)_2$	Formacetic Acid
	311	$C(OH)_3.CHOH.CH_2OH$	Glyceric Acid
	221	$CH(OH)_2.C(OH)_2.CH_2.OH$	Unknown
	212	$CH(OH)_2.CH(OH).CH(OH)_2$	Unknown
VI:	303	$C(OH)_3.CH_2.C(OH)_3$	Malonic Acid
	321	$C(OH)_3.C(OH)_2.CH_2OH$	Hydroxypyroracemic Acid (p. 543)
	312	$C(OH)_3.CHOH.CH(OH)_2$	Tartronic Semialdehyde (p. 543)
	222	$CH(OH)_2.C(OH)_2.CH(OH)_2$	Mesoxalic Dialdehyde
VII:	322	$C(OH)_3.C(OH)_2.CH(OH)_2$	Unknown
	313	$C(OH)_3.CH(OH).C(OH)_3$	Tartronic Acid
VIII:	323	$C(OH)_3.C(OH)_2.C(OH)_3$	Mesoxalic Acid

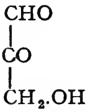
Of the 29 possible hydroxyl substitution products of propane indicated in the above tables by numbers, five are underlined, n-propyl alcohol, isopropyl alcohol, propylene glycol, trimethylene glycol and glycerol. The remaining 24 can be looked on as being oxidation products of these. The dotted line connects these products with the parent substance. Two are derivable from n-propyl alcohol, one from isopropyl alcohol, five from propylene glycol and from trimethylene glycol; eleven from glycerol. The following table shows them rearranged according to their usual formulæ—that is, their ortho-formulæ minus water:

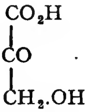

$$\begin{array}{l}CH_2OH\\ |\\ CH.OH\\ |\\ CH_2OH\end{array}$$
(111) Glycerol.


$$\begin{array}{l}CHO\\ |\\ CHOH\\ |\\ CH_2OH\end{array}$$
(211) Glyceric Aldehyde.


$$\begin{array}{l}CO_2H\\ |\\ CHOH\\ |\\ CH_2OH\end{array}$$
(311) Glyceric Acid.


$$\begin{array}{l}CH_2OH\\ |\\ CO\\ |\\ CH_2.OH\end{array}$$
(121) Dihydroxyacetone.

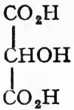

$$\begin{array}{l}CHO\\ |\\ CO\\ |\\ CH_2.OH\end{array}$$
(221) Unknown.


$$\begin{array}{l}CO_2H\\ |\\ CO\\ |\\ CH_2.OH\end{array}$$
(321) Hydroxypyroracemic Acid.


$$\begin{array}{l}CO_2H\\ |\\ CHOH\\ |\\ CHO\end{array}$$
(312) Tartronic Semialdehyde.

$$\begin{array}{l}CHO\\|\\CHOH\\|\\CHO\end{array}$$

(212)
Unknown.



$$\begin{array}{l}CO_2H\\|\\CHOH\\|\\CO_2H\end{array}$$

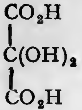
(313)
Tartronic Acid.

$$\begin{array}{l}CHO\\|\\CO\\|\\CHO\end{array}$$

(222)
Mesoxalic Dialdehyde.

$$\begin{array}{l}CO_2H\\|\\CO\\|\\CHO\end{array}$$

(322)
Mesoxalic Semialdehyde.



$$\begin{array}{l}CO_2H\\|\\C(OH)_2\\|\\CO_2H\end{array}$$

(323)
Mesoxalic Acid.

Glyceric acid, tartronic acid, and mesoxalic acid are the only accurately known representatives of these eleven oxidation products of glycerol. Glyceric aldehyde, dihydroxyacetone, hydroxyacemic acid, tartronic semialdehyde, mesoxalic di- and semi- aldehydes have all been investigated to only a small extent.

Three hydrogen atoms in glycerol can be replaced by alcohol or acid radicals, producing ethers and esters:

$$C_3H_5\begin{cases}OH\\OH\\O.C_2H_3O\end{cases}\qquad C_3H_5\begin{cases}OH\\O.C_2H_3O\\O.C_2H_3O\end{cases}\qquad C_3H_5\begin{cases}O.C_2H_3O\\O.C_2H_3O\\O.C_2H_3O\end{cases}$$

Acetin. Diacetin. Triacetin.

The haloid esters are the halohydrins:

$C_3H_5(OH)_2Cl$ Monochlorhydrin. $C_3H_5(OH)Cl_2$ Dichlorhydrin. $C_3H_5Cl_3$ Trichlorhydrin.

Formation.—The trihydric alcohols are obtained (1) by heating the bromides of the unsaturated alcohols with water; or—

(2) By oxidizing the unsaturated alcohols with potassium permanganate (B. **28**, R. 927).

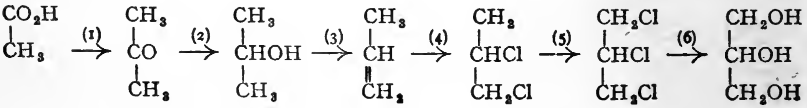
(3) Aldehydes having the constitution RCH_2CHO condense with formaldehyde in the presence of lime to form triprimary glycerols:

$$RCH_2CHO+3CH_2O+H_2O=RC(CH_2OH)_2CH_2OH+HCOOH.$$

(4) Dialkyl ethers of glycerol are prepared by the magnesium organic synthesis from carboxylic esters or alkoxyketones and chloro- or iodo-substituted ethers.

Glycerol [Propanetriol], $CH_2OH.CHOH.CH_2OH$, m.p. 17° (solidifies below 0°), b.p.$_{760}$ 290° almost without decomposition, b.p.$_{12}$ 170°, $D_{15}=1{\cdot}265$, is produced (1) in small quantities in the alcoholic fermentation of sugar; hence is contained in wine (p. 114). (2) It is prepared by hydrolysis of oils and fats, which are glycerol esters of the fatty acids. Glycerol is also formed (3) from synthetic allyl trichloride by heating it with water, and (4) from allyl alcohol when it is oxidized with potassium permanganate. (5) Also, by the reduction of dihydroxyacetone.

Historical.—*Scheele* discovered glycerol in 1779, when he saponified olive oil with litharge, in making lead plaster. *Chevreul,* who recognized ester-like derivatives of glycerol in the fats and fatty oils, introduced the name glycerol, and in 1813 pointed to similarities between it and alcohol. The composition of glycerol was established in 1836, by *Pelouze*. *Berthelot* and *Lucca* (1853), and later *Würtz* (1855), explained its constitution, and proved that it was the simplest trihydric alcohol, the synthesis of which *Friedel* and *Silva* (1872) effected from acetic acid:



$$\begin{array}{l}CO_2H\\|\\CH_3\end{array}\xrightarrow{(1)}\begin{array}{l}CH_3\\|\\CO\\|\\CH_3\end{array}\xrightarrow{(2)}\begin{array}{l}CH_3\\|\\CHOH\\|\\CH_3\end{array}\xrightarrow{(3)}\begin{array}{l}CH_3\\|\\CH\\\|\\CH_2\end{array}\xrightarrow{(4)}\begin{array}{l}CH_3\\|\\CHCl\\|\\CH_2Cl\end{array}\xrightarrow{(5)}\begin{array}{l}CH_2Cl\\|\\CHCl\\|\\CH_2Cl\end{array}\xrightarrow{(6)}\begin{array}{l}CH_2OH\\|\\CHOH\\|\\CH_2OH\end{array}$$

(1) Acetone is obtained from calcium acetate. (2) Acetone by reduction passes into isopropyl alcohol. (3) Propylene results when anhydrous zinc chloride withdraws water from isopropyl alcohol. (4) Chlorine and propylene yield propylene chloride. (5) Propylene chloride and iodine chloride unite to form propenyl trichloride or allyl trichloride, the trichlorhydrin of glycerol. (6) Glycerol is produced when trichlorhydrin is heated with much water to 160° (B. **6**, 969). Metallic iron and bromine convert propylene bromide into tribromhydrin, which silver acetate changes to triacetin. Bases saponify the latter and glycerol results (B. **24**, 4246).

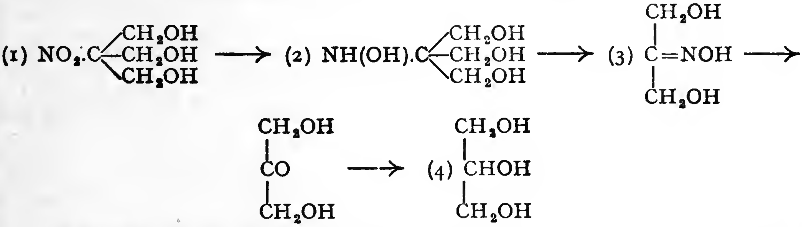
A second method of synthesizing glycerol is that of *O. Piloty* (1897), which starts from *L. Henry's* nitro-tert.-butyl glycerol, the condensation product of formaldehyde and nitromethane. (1) Nitro-tert.-butyl glycerol is reduced to hydroxylamino-tert.-butyl glycerol, which is then (2) oxidized by HgO to dihydroxyacetone oxime:

$$(CH_2OH)_3C.NH(OH)+2O=(CH_2OH)_2C{:}NOH+HCO_2H+H_2O\,;$$

(3) bromine water converts this substance into dihydroxy-acetone:

$$2(CH_2OH)_2C:NCH+2Br_2+H_2O=2(CH_2OH)_2C:O+N_2O+4HBr_2\,;$$

which, finally, is reduced to glycerol by sodium amalgam (B. **30**, 3161):



Preparation.—Glycerol is produced in large quantities during the saponification of fats and oils in soap and candle manufacture. When the process is carried out with superheated steam, an aqueous solution of glycerol and free insoluble fatty acids are formed. Pure glycerol is produced from its solution by distillation under reduced pressure.

Properties.—Anhydrous glycerol is a thick, colourless syrup, which slowly solidifies at 0°, forming transparent crystals. With superheated steam it distils entirely unaltered. It has a pure, sweet taste, hence the name glycerol, and it is very hygroscopic, mixing in every proportion with water and alcohol. It is fairly soluble (1 : 3) in acetone (A. **335**, 319), but insoluble in ether. It dissolves the alkalis, alkali earths and many metallic oxides, forming with them, in all probability, metallic compounds similar to the alcoholates (p. 116). *Copper Sodium Glycerate,* $(C_3H_5O_3CuNa)_2+3H_2O$, is obtained from glycerol, copper oxide and sodium hydroxide solution (B. **31**, 1453).

Reactions.—(1) When glycerol is distilled with dehydrating substances, like sulphuric acid and phosphorus pentoxide, boric acid, or preferably potassium hydrogen sulphate, it decomposes into water and acroleïn (p. 214).

(2) When heated to 430–450°, glycerol decomposes partly into *acroleïn* and partly into *acetol:*

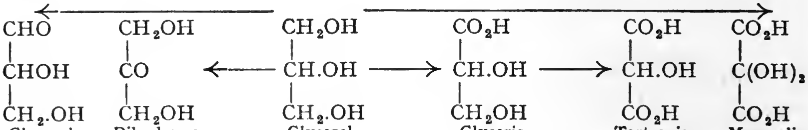
$$CH_2{:}CH.CHO\xleftarrow{-2H_2O}CH_2(OH).CH(OH).CH_2(OH)\xrightarrow{-H_2O}CH_3.CO.CH_2OH$$

(comp. transformation of glycols into aldehydes and ketones, p. 312); the acetol partially decomposes into acetaldehyde and formaldehyde which, like acroleïn itself, unite with glycerol to form acetal-like substances (A. **335**, 209).

(3) When sodium glycerol or glycerol and sodium hydroxide are heated together, hydrogen is evolved and mainly *lactic* acid is formed, together with lower fatty acids, methyl alcohol and propylene glycol (A. **335**, 279).

(4) Platinum black and air, mercuric oxide and alkali or dilute nitric acid convert glycerol into glyceric and tartronic acids; sodium and bismuth nitrate oxidize it to mesoxalic acid (B. **27**, R. 666). Energetic oxidation produces oxalic, glycollic and glyoxylic acids (p. 400); silver oxide gives rise to formic and glycollic acids (A. **335**, 316).

(5) Moderated oxidation (with nitric acid or bromine) produces *glycerose*, which consists chiefly of glyceraldehyde and dihydroxyacetone, $CO(CH_2.OH)_2$. This unites with HNC and forms trihydroxybutyric acid:



$$\begin{array}{l}CHO\\|\\CHOH\\|\\CH_2.OH\end{array}\quad\begin{array}{l}CH_2OH\\|\\CO\\|\\CH_2OH\end{array}\xleftarrow{\quad}\begin{array}{l}CH_2OH\\|\\CH.OH\\|\\CH_2.OH\end{array}\xrightarrow{\quad}\begin{array}{l}CO_2H\\|\\CH.OH\\|\\CH_2OH\end{array}\xrightarrow{\quad}\begin{array}{l}CO_2H\\|\\CH.OH\\|\\CO_2H\end{array}\quad\begin{array}{l}CO_2H\\|\\C(OH)_2\\|\\CO_2H\end{array}$$

Glyceraldehyde. Dihydroxyacetone. Glycerol. Glyceric Acid. Tartronic Acid. Mesoxalic Acid.

(6) Phosphorus iodide or hydriodic acid converts it into allyl iodide, isopropyl iodide, and propylene (p. 104). (7) In the presence of yeast at 20–30° it ferments, forming propionic acid. By *Schizomycetes fermentation*, induced by *Butyl bacillus* (B. **30**, 451; **41**, 1412), normal butyl alcohol (p. 118), trimethylene glycol and formic and lactic acids result (p. 314).

(8) When glycerol is distilled with ammonium chloride, ammonium phosphates and other ammonium salts, β-picoline (Vol. II.), as well as 2,5-dimethyl pyrazine (Vol. II.), results. Under certain conditions it is only the latter which is produced (**24**, 4105; B. **26**, R. 585; **27**, R. 436, 812; A. **335**, 223).

Uses.—Glycerol is applied as such in medicine. It is also used in gas meters. Duplicating plates and hectographs consist of mixtures of gelatin and glycerol.

The bulk of glycerol is consumed in the manufacture of nitroglycerine (p. 529).

Glycerol Homologues.—1,2,3-*Butyl Glycerol*, $CH_3.CH(OH).CH(OH).CH_2OH$, b.p.$_{27}$ 172–175°, is prepared from crotonylalcohol dibromide (p. 124).

[1,2,3-*Pentanetriol*], $C_2H_5.CH(OH).CH(OH).CH_2.OH$, b.p.$_{63}$ 192°; [2,3,4-*Pentanetriol*], $CH_3.CH(OH).CH(OH).CH(OH).CH_3$, b.p.$_{27}$ 180°; β-*Ethyl Glycerol*, $CH_3.CH_2C(OH)(CH_2OH)_2$, b.p.$_{68}$ 186–189°. These and other glycerols result upon oxidizing unsaturated alcohols with potassium permanganate (B. **27**, R. 165; **28**, R. 927). *Pentaglycerol*, $CH_3C(CH_2OH)_3$, m.p. 199°, is obtained by the action of lime on propyl aldehyde and formaldehyde (A. **276**, 76). *Dimethyl Pentaglycerol*, $(CH_3)_2CHC(CH_2OH)_3$, m.p. 83°, is prepared from isovaleraldehyde and formaldehyde by the action of lime (B. **36**, 1341). These substances are *triprimary* glycerols.

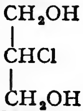
[1,4,5-*Hexanetriol*], $CH_3.CH(OH).CH(OH).CH_2.CH_2.CH_2OH$, b.p.$_{10}$ 181°, and some other isomers and higher homologues have been obtained from the addition products of bromine and hypochlorous acid with the corresponding unsaturated alcohols.

A. GLYCEROL ESTERS OF INORGANIC ACIDS

(*a*) **Glycerol Haloid Esters.**—These are called halohydrins (p. 124). There are two possible isomeric mono- and di-halohydrins. They are distinguished as α-halohydrins and β-halohydrins :

$$\begin{array}{l} CH_2Cl \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

α-Chlorhydrin.

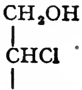


$$\begin{array}{l} CH_2OH \\ | \\ CHCl \\ | \\ CH_2OH \end{array}$$

β-Chlorhydrin.

$$\begin{array}{l} CH_2Cl \\ | \\ CHOH \\ | \\ CH_2Cl \end{array}$$

α-Dichlorhydrin.



$$\begin{array}{l} CH_2OH \\ | \\ CHCl \\ | \\ CH_2Cl \end{array}$$

β-Dichlorhydrin.

The monohalohydrins may also be regarded as halogen substitution products of propylene and trimethylene glycol, whilst the dihalohydrins are probably the dihalogen substitution products of propyl and isopropyl alcohol (p. 117).

α-Monohalohydrins are formed when the halogen acids act on glycerol, and by the interaction of water and epihalohydrins. *α-Chlorhydrin*, $CH_2OH.CHOH.CH_2Cl$, b.p.$_{18}$ 139°. *α-Bromhydrin*, b.p.$_{10}$ 180°. *α-Iodohydrin*, b.p.$_{24}$ 62° (A. **335**, 237).

β-Chlorhydrin, $CH_2OH.CHCl.CH_2OH$, b.p.$_{18}$ 146°, is obtained from allyl alcohol and ClOH (C. 1897, I. 741).

α-Dihalohydrins are produced when the halogen acids (A. **208**, 349) act on glycerol, and on the epihalohydrins (p. 532) (B. **10**, 557). Potassium iodide changes the chlorine derivative into the iodine compound.

α-Dichlorhydrin, $CH_2Cl.CHOH.CH_2Cl$, b.p. 174°, $D_{19}=1·367$, is a liquid, with ethereal odour. It is not very soluble in water, but dissolves readily in alcohol and ether. When heated with hydriodic acid it becomes converted into isopropyl iodide; sodium amalgam produces isopropyl alcohol. When sodium acts on an ethereal solution of α-dichlorhydrin, we do not get trimethylene alcohol, but allyl alcohol as a result of molecular transposition (B. **21**, 1289). Chromic acid oxidizes it to β-dichloracetone (p. 224) and chloracetic acid. Potassium hydroxide converts it into epichlorhydrin (p. 532).

α-Dibromhydrin, $CH_2Br.CHOH.CH_2Br$, b.p. 219°; $D_{18}=2·11$.

α-Di-iodhydrin, $D=2·4$, solidifies at −15°, is a thick oil.

It readily loses HI and polymerizes to *β-iodopropionaldehyde* (C. 1900, II. 169). *β-Ethyl α-Dichlorohydrin*, $C_2H_5C(OH)(CH_2Cl)_2$, b.p.$_{15}$ 77°, is formed from sym.-dichloracetone and ethyl magnesium bromide (C. 1906, I. 1471).

The **β-Dihalohydrins** result from the addition of halogens to allyl alcohol.

β-Dichlorhydrin, b.p. 183°, $D_0=1·379$, is converted by sodium into allyl alcohol. Hydriodic acid changes it to isopropyl iodide; fuming nitric acid oxidizes it to αβ-dichloropropionic acid.

Both dichlorhydrins are changed to epichlorhydrin by alkalis.

β-Dibromhydrin, b.p. 212–214°.

Trihalohydrins are formed when halogens are added to the allyl halides; also in the action of phosphorus halides on the dihalohydrins, and when iodine chloride acts on propylene chloride, and bromine and iron on propylene bromide and trimethylene bromide (B. **24**, 4246).

Trichlorhydrin, Glyceryl Chloride, 1,2,3-Trichloropropane, $CH_2Cl.CHCl.CH_2Cl$, b.p. 158°.

Tribromhydrin, m.p. 16°, b.p. 220°, is converted by silver acetate into glycerol triacetyl ester. When this is saponified it yields glycerol (p. 527).

(*b*) **Glycerol Esters of the Mineral Acids containing Oxygen.**—The neutral nitric acid ester (nitroglycerol)—*nitroglycerine* (discovered by *Sobrero* in 1847)—is the most important member of this class.

Nitroglycerine, *Glycerol Nitrate*, $CH_2(ONO_2).CH(ONO_2).CH_2(ONO_2)$, m.p. 16°, $D=1·6$, is produced by the action of a mixture of sulphuric and nitric acids on glycerol. The latter is added, drop by drop, to a well-cooled mixture of two parts of fuming nitric acid and three parts of concentrated sulphuric acid. On standing the nitroglycerol rises, and, after separation, is poured into water.

The heavy oil (nitroglycerine) is washed with water and dried by means of calcium chloride.

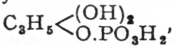
Nitroglycerine is a colourless oil, which is easily volatilized at 160° (15 mm. pressure) (B. **29**, R. 41). It has an acrid taste, and is poisonous when taken internally. It is sparingly soluble in water, dissolves with difficulty in cold alcohol, but is easily soluble in wood spirit and ether. Heated quickly, or upon percussion, it explodes very violently; mixed with *kieselguhr* it forms *dynamite*, and with nitrocellulose, *smokeless powder*.

Alkalis convert nitroglycerine into glycerol and nitric acid; ammonium sulphide also regenerates glycerol. Both reactions prove that nitroglycerine is not a nitro-compound, but a nitric acid ester.

Partial nitration of glycerol or partial hydrolysis of nitroglycerine by dilute sulphuric acid produces the two possible *dinitroglycerines*, $C_3H_5(OH)(ONO_2)_2$, oils, which are not explosive; and also the two *mononitroglycerines*, $C_3H_5(OH)_2(ONO)_2$, m.ps. 59° and 54°; these substances are easily soluble in water (B. **41**, 1107).

Glycerol Nitrite, $C_3H_5(O.NO)_3$, is formed by the action of N_2O_3 on glycerol. It is isomeric with *trinitropropane* (B. **16**, 1697).

Glycerol Sulphuric Acid, $CH_2OH.CHOH.CH_2.OSO_3H$, is obtained from glycerol and sulphuric acid. *Propane-1,2,3-trisulphonic Acid*, $C_3H_5(SO_2H)_3$, however, is formed from tribromhydrin and ammonium sulphite (C. 1904, II. 944).



Glycerol Phosphoric Acid, $C_3H_5<\begin{matrix}(OH)_2\\O.PO_3H_2\end{matrix}$, occurs combined with the fatty acids and choline as lecithin (p. 531) in the yolk of eggs, in the brain, in the bile, and in the nerve tissue. It is produced on mixing glycerol with metaphosphoric acid. The free acid is a thick syrup, which decomposes into glycerol and phosphoric acid when it is heated with water. It yields easily soluble salts with two equivalents of metal. The calcium salt is more insoluble in hot than in cold water; on boiling its solution, it is deposited in glistening leaflets (C. 1899, I. 1105). For *mono-acidic* and *neutral glycerol phosphate*, $C_3H_5.O_3PO$, see C. 1904, I. 431. For the action of PCl_3 on glycerol, see C. 1902, I. 1048.

Glycerol *mercaptans* are produced when chlorhydrins are heated with alcoholic solutions of potassium hydrosulphide.

B. GLYCEROL FATTY ACID ESTERS, GLYCERIDES

(*a*) **Formic Acid Esters.** Monoformin, $C_3H_5(OH)_2OCHO$, is volatile under diminished pressure. It is supposed that it is formed on heating oxalic acid and glycerol. When it is heated alone it breaks down into allyl alcohol (p. 123), water, and carbon dioxide. *Diformin* is most certainly produced under these conditions. Monoformin also results from the action of *d*-monochlorhydrin on sodium formate. **Diformin**, $C_3H_5(OH).(O.CHO)_2$, b.p.$_{20-30}$ 163–166°.

(*b*) **Acetic Esters**, or **Acetins**, result when glycerol and acetic acid are heated together (C. 1897, II. 474). *Monacetin*, b.p.$_{2-3}$ 131°. *Diacetin*, $C_3H_5(O.COCH_3)_2(OH)$, b.p. 159° (B. **25**, 3466). *Triacetin*, $C_3H_5(O.COCH_3)_3$, b.p. 258°, occurs in small quantities in the seed of *Euonymus europæus*, and has also been obtained from tribromhydrin (p. 529). *Dichloromonacetin* and *monochlorodiacetin* (C. 1905, I. 12).

(*c*) **Tributyrin**, $C_3H_5(OC_4H_7O)_3$, b.p.$_{10}$ 185° (C. 1899, II. 21; 1900, II. 215), occurs in cow's butter (p. 259).

(*d*) **Glycerides of Higher Fatty Acids** occur, as already stated (p. 264), in the vegetable and animal fatty oils, fats, and tallows. They can be artificially obtained by heating glycerol with the fatty acids (C. 1899, II. 20), or from tribromhydrin and fatty acid salts (C. 1900, II. 215). The mono- and di-esters (*monostearin*, *dipalmitin*, etc.) are prepared from mono- or di-chlorhydrins and salts of the fatty acids, or by esterifying glycerol and the fatty acids by means of concentrated sulphuric acid (C. 1903, I. 133; B. **38**, 2284). If esterification is completed with different acids *mixed glycerides*, such as *palmitodistearin*, are formed, which occur to a certain extent in natural fats (B. **36**, 2766).

Glycerides are very slightly soluble in cold alcohol, but easily so in ether. They are saponified by alkalis or lead oxide (comp. p. 264) (C. 1899, II. 1699).

When boiled with alcohols in presence of a little alkali or acid, the glycerides are, to a great extent, converted into glycerol and fatty esters of the alcohols (C. 1907, I. 151; 1908, I. 1157; II. 495).

The most important glycerides are:

Trimyristin, or **Myristin,** *Glycerol Myristic Ester,* $C_3H_5(O.C_{14}H_{27}O)_3$, m.p. 55°, occurs in spermaceti, in nutmeg butter, and chiefly in oil nuts (from *Myristica surinamensis*), from which it is most readily obtained (B. **18,** 2011). It crystallizes from ether in glistening needles. It yields myristic acid (p. 261) when saponified.

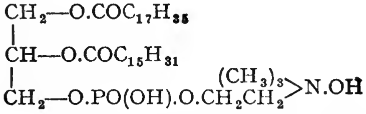
Tripalmitin, $C_3H_5(O.C_{16}H_{31}O)_3$, m.p. (45°) 65°, is found in most fats, especially in palm oil; it can be separated from olive oil at low temperatures.

Tristearin, $C_3H_5(O.C_{18}H_{35}O)_3$, m.p. (55°) 71·5°, occurs mainly in solid fats (tallows). It can be obtained by heating glycerol and stearic acid to 280–300°. It crystallizes from ether in shining leaflets.

On the phenomenon of the "double melting-point" of palmitin and stearin, see C. 1902, I. 1196.

Trioleïn, or **Oleïn,** $C_3H_5(O.C_{18}H_{33}O)_3$, solidifies at −6°. It is found in oils, like olive oil. It is oxidized on exposure to the air. Nitrous acid converts it into the isomeric *elaïdin,* m.p. 36° (p. 301).

Lecithins are widely distributed in the animal organism and occur especially in the brain, in the nerves, the blood corpuscles, and the yolk of egg, from which stearin-palmitic lecithin is most easily prepared. Lecithin occurs in the seeds of plants (B. **29,** 2761). It is a wax-like mass, easily soluble in alcohol and ether, and crystallizes in fine needles. It swells up in water and forms an opalescent solution, from which it is reprecipitated by various salts. It units with bases and acids to salts, forming a sparingly soluble double salt, $(C_{42}H_{84}NPO_9.HCl)_2.$-$PtCl_4$, with platinic chloride. Lecithin is decomposed into choline, glycerophosphoric acid (see above), stearic acid, and palmitic acid, when it is boiled with acids or barium hydroxide solution. Therefore we assume it to be an ethereal compound of choline with glycerophosphoric acid, combined as glyceride with stearic and palmitic acids:



$$\begin{array}{l} CH_2—O.COC_{17}H_{35} \\ | \\ CH—O.COC_{15}H_{31} \\ | \\ CH_2—O.PO(OH).O.\begin{matrix}(CH_3)_3 \\ CH_2CH_2\end{matrix}>N.OH \end{array}$$

Lecithin is optically active—dextro-rotatory. When heated in alcoholic solution to 90–100° it is racemized, and from this i-*lecithin,* l-*lecithin* can be separated by *lipase* (C. 1901, II. 193; 1906, II. 493).

The distearin and dioleo- compounds are also known. *Protagon,* a substance obtained from the brain, appears to be closely related to the *lecithins.*

Glycerol Ethers: 1. Alkyl Ethers.

Mixed ethers of glycerol with alcohol radicals are obtained by heating the mono- and dichlorhydrins with sodium alcoholates.

Epichlorhydrin, sodium hydroxide solution, and an alcohol form glycerol dialkyl ether (C. 1898, I. 237).

Monoethylin, $CH_2OH.CHOH.CH_2OC_2H_5$, b.p. 230°, is soluble in water. *Glycerol Dimethyl Ether,* b.p. 169°. *Diethylin,* $CH_2OH.CH(OC_2H_5)CH_2OC_2H_5$, b.p. 191°, dissolves with difficulty in water, and has an odour resembling that of peppermint. *Triethylin,* $C_3H_5(OC_2H_5)_3$, b.p. 185°, is insoluble in water.

Allylin, $CH_2OH.CHOH.CH_2C_3H_5$, b.p. 225–240°, is produced by heating glycerol with oxalic acid (B. **14,** 1946, 2270), and is present in the residue from the preparation of allyl alcohol (p. 123). It is a thick liquid. *Diallylin,* $HO.C_3H_5(OC_3H_5)_2$, b.p. 225°–227, is produced when sodium allylate acts on epichlorhydrin (B. **25,** R. 506).

Dialkyl Ethers of Homologous Glycerols.

Fatty acid esters are condensed with chloromethyl alkyl ethers to form dialkyl ethers of homologous glycerols by means of magnesium, which can be rendered more active by means of $HgCl_2$ (C. 1907, I. 871):

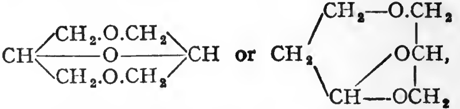
$$RCOOC_2H_5+2ClMgCH_2OC_2H_5 \longrightarrow RC(OH)(CH_2OC_2H_5)_2.$$

These *diethylines* yield acroleïns, similarly to glycerol itself, when treated with oxalic acid: two molecules of alcohol are eliminated and α-alkyl acroleïns result (comp. p. 214).

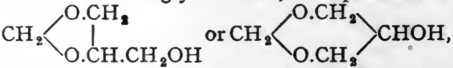
Ethyl Glycerol Diethyl Ether, $C_2H_5C(OH)(CH_2OC_2H_5)_2$, b.p. 195°, is prepared from propionic ester, chloromethyl ethyl ether and magnesium. *Propyl Glycerol Diethylin*, b.p. 210°; the *Isobutyl*, b.p. 215°; n-*Amyl*, b.p.$_{13}$ 119°; *Hexyl*, b.p.$_{15}$ 136°; *Octyl*, b.p.$_{15}$ 160°; *Decenyl Glycerol Dimethylin*, b.p.$_{12}$ 180°.

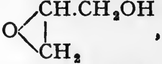
1,7-*Dimethoxyheptane*-4-*ol*, $HC(OH)[CH_2CH_2CH_2OCH_3]_2$, b.p. 247°, is prepared from formic ester, γ-methoxypropyl iodide and magnesium. It is a liquid possessing a very bitter taste (C. 1906, I. 332).

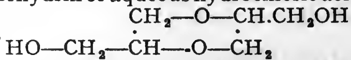
2. **Cyclic Ethers:**

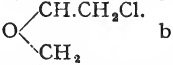
Glycerol Ether,  b.p. 171°, is formed when glycerol is heated to 270–330°, with a little ammonium chloride (A. **335**, 209); also, together with diallylin, from epichlorhydrin and sodium allylate (see above). It is readily soluble in water, and is hydrolyzed with difficulty.

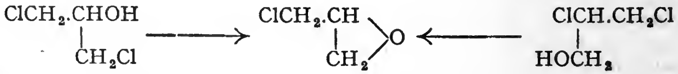
An isomeric substance, m.p. 124°, has been obtained as a by-product of the preparation of pyridine bases from glycerol and ammonium phosphate (comp. p. 528) (C. 1897, I. 583).

Glycerol derivatives resembling the acetals are formed when formaldehyde, acetaldehyde, acroleïn, benzaldehyde, or acetone act on glycerol hot, or in presence of hydrochloric acid. *Formal Glycerol*,  b.p. 193° (A. **289**, 29; **335**, 209). *Acetal Glycerol*, $HOC_3H_5O_2{>}CHCH_3$, b.p.$_{18}$ 86°. *α-Acroleïn Glycerol*, $HO.C_3H_5O_2{>}CH.CH{:}CH_2$, is isomeric with glycerol ether or β-acroleïn glycerol (*q.v.*). *Benzal Glycerol*, $HOC_3H_5O_2{>}CHC_6H_5$, m.p. 66°. *Acetone Glycerol*, $HOC_3H_5O_2{>}C(CH_3)_2$, b.p.$_{11}$ 83° (B. **27**, 1536; **28**, 1169).

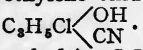
Glycide Compounds: Glycide, *Epihydrin Alcohol*,  , b.p. 162°, D_0=1·165, is isomeric with acetyl carbinol (p. 341). This body shows the properties both of ethylene oxide and of ethyl alcohol. It is obtained from its acetate by the action of sodium hydroxide or barium hydroxide. Glycide and its acetate reduce ammoniacal silver solutions at ordinary temperatures.

Glycerol also forms *polyglycerols*. Thus glycerol yields **Diglycerol,** $(HO)_2.C_3H_5OC_3H_5(OH)_2$, when it is treated with chlorhydrin or aqueous hydrochloric acid at 130°. The polymer of glycide, *Diglycide*, 
$$\begin{matrix} & CH_2\text{—O—}CH.CH_2OH \\ HO\text{—}CH_2\text{—}CH\text{—O—}CH_2 & \end{matrix}$$
(?), results from the action of sodium acetate on epichlorhydrin in absolute alcohol, and the subsequent hydrolysis of diglycide acetate with sodium hydroxide.

Epichlorhydrin,  b.p. 117°, D_0=1·203, is isomeric with monochloracetone, and constitutes the parent substance for the preparation of the glycide compounds. It is obtained from both dichlorhydrins by the action of alkali hydroxides (analogous to the formation of ethylene oxide from glycol chlorhydrin) (p. 319):

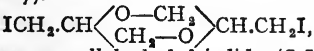


It is a very mobile liquid, insoluble in water. Its odour resembles that of chloroform, and its taste is sweetish and burning. It forms α-dichlorhydrin with concentrated hydrochloric acid. PCl_5 converts it into trichlorhydrin. Continued heating with water to 180° changes it to α-monochlorhydrin. Concentrated nitric acid oxidizes it to β-chlorolactic acid. Metallic sodium converts it into sodium allylate, $CH_2{=}CH.CH_2ONa$.

Like ethylene oxide, epichlorhydrin combines with HNC to the hydroxy-cyanide,  $C_3H_5Cl\left\langle\begin{matrix}OH\\CN\end{matrix}\right.$.

Epibromhydrin, C_3H_5OBr, b.p. 130–140°, is prepared from the dibromhydrin.

Epi-iodohydrin, C_3H_5OI, b.p.$_{12}$ 62°, is prepared from epichlorhydrin by the action of KI and alcohol, and subsequent treatment with aqueous alkali hydroxides. *Epihydrin-ether*, $[O<C_3H_5]_2O$, b.p.$_{22}$ 103°, is produced from the above by means of silver oxide; and *Nitroglycide*, $NO_2.OC_3H_5>O$, b.p.$_{15}$ 63°, by silver nitrate. It also results when alkali acts on either of the two dinitroglycerols (p. 530) (A. **335**, 238; B. **41**, 1117).

Di-epi-iodohydrin,  $ICH_2.CH\left\langle\begin{matrix}O—CH_2\\CH_2—O\end{matrix}\right\rangle CH.CH_2I$, m.p. 160°, is formed when iodine acts on *mercury allyl alcohol iodide*, $(C_3H_5O.HgI)_2$. This body, as well as *mercury propylene-glycol iodide*, $IHg.CH_2CH(OH)CH_2OH$, is also obtained from allyl alcohol and mercury salts (comp. Mercury Ethanol Iodide, p. 326) (B. **34**, 1385, 2911).

Epiethylin, Ethyl Glycide Ether, $O<C_3H_5.OC_2H_5$, b.p. 129°, and *Amyl Glycide Ether*, b.p. 188°, are produced from the respective ethers of chlorhydrin by distillation with potassium hydroxide (A. **335**, 231). *Glycide Acetate*, $O<C_3H_5.OCOCH_3$, b.p. 169°, is formed from epichlorhydrin and anhydrous potassium acetate.

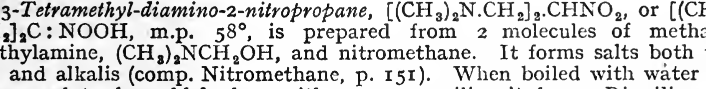
Nitrogen Derivatives of the Glycerols.

Nitroisobutyl Glycol, $CH_3C.(NO_2)(CH_2OH)_2$, b.p. 140°, is formed from nitroethane and formaldehyde (B. **28**, R. 774).

1-*Aminopropane Diol*, $NH_2.CH_2CH(OH)CH_2OH$, b.p.$_{335}$ 238°, is formed from glycide and aqueous ammonia. Similarly, the 1-*alkyl aminopropane diols* can be prepared; tertiary amines react with glycerol α-chlorhydrin to form quarternary ammonium chlorides, *e.g.* $(C_2H_5)_3N(Cl)CH_2CHOH.CH_2OH$ (B. **33**, 3500). 2-*Aminopropane Diol*, $HOCH_2.CH(NH_2).CH_2OH$, is formed when dihydroxyacetone oxime is reduced (B. **32**, 751).

2-*Amino*-tert.-*butane Diol*, $CH_3C(NH_2)(CH_2OH)_2$ (C. 1908, I. 816).

From 1,3-*Diamino-2-propanol* is derived the local anæsthetic *Alypin*, $C_6H_5CO.OCH[CH_2N(CH_3)_2]_2$ (C. 1905, II. 1551); also 1,3-*Dianilinopropanol*, $(C_6H_5NHCH_2)_2CHOH$, from aniline and epichlorhydrin (B. **37**, 3034); also, finally, *Trimethylene-imino-2-sulphonic acid*. This substance is obtained from *bromomethyl taurine*, a decomposition product of the *thiazoline* derivative obtained from allyl-mustard oil dibromide (B. **39**, 2891).



Triaminopropane, $CH_2NH_2.CHNH_2,CH_2NH_2$, b.p.$_9$ 93°, is prepared from *Glycerol Triurethane*, $C_3H_5(NHCO_2C_2H_5)_3$, m.p. 92°, which is formed from the action of absolute alcohol on the triazide of tricarballylic acid (J. pr. Ch. [2] **62**, 240).

1,3-*Tetramethyl-diamino-2-nitropropane*, $[(CH_3)_2N.CH_2]_2.CHNO_2$, or $[(CH_3)_2NCH_2]_2C:NOOH$, m.p. 58°, is prepared from 2 molecules of methanol-dimethylamine, $(CH_3)_2NCH_2OH$, and nitromethane. It forms salts both with acids and alkalis (comp. Nitromethane, p. 151). When boiled with water it is decomposed to formaldehyde; with aqueous aniline it forms *Dianilinonitropropane*, $(C_6H_5NHCH_2)_2CHNO_2$; by reduction with tin chloride it yields *Tetramethyl-1,3,2-triamino-propane*, $[(CH_3)_2NCH_2]_2CHNH_2$, b.p. 175° (B. **38**, 2037).

2. DIHYDROXY-ALDEHYDES.

Glycerol Aldehyde [*Propane Diolal*], $CH_2OH.CHOH.CHO$, m.p. 138°, is prepared in the pure state by hydrolysis of its *acetal* (see below) with dilute sulphuric acid. When treated with alcohol and hydrochloric acid, it is reconverted into the parent substance. It crystalizes in needles from dilute methyl alcohol, and is almost insoluble in alcohol and ether. It reduces Fehling's solution in the cold, and forms a characteristic compound with phloroglucinol (Vol. II.) with loss of water. The *Glycerol Acetal*, $CH_2OH.CHOH.CH(OC_2H_5)_2$, b.p.$_{21}$ 130°, is best obtained by oxidation of acroleïn acetal (p. 215) with permanganate.

Glycerol Aldehyde Oxime, $CH_2OH.CHOH.CH:NOH$, is an oil. When warmed with alkalis it loses water and hydrocyanic acid, forming glycol aldehyde (p. 337) (comp. the carbohydrates). In the solid form both glycol aldehyde and glycerol aldehyde are apparently to be looked on as dimolecular polymers (B. **33**, 3095).

2-Chloro-3-hydroxy-propionacetal, $CH_2(OH).CHCl.CH(OCH_3)_2$, b.p.$_{11}$ 98°, is formed from acroleïn acetal and HClO. Oxidation converts it into 2-chloro-3-dimethoxy-propionic acid, $(CH_3O)_2CH.CHClCOOH$; reaction with ammonia produces *2-Hydroxy-3-amino-propionacetal*, $CH_2(NH_2).CH(OH)CH(OCH_3)_2$, m.p. 55–58°, b.p.$_{11}$ 111°, with intermediate formation of open ethylenoxy-compound. This acetal gives rise to the hydrochloride of *β-Aminolactic Aldehyde*, $NH_2CH_2CH(OH)CHO$, which, on oxidation yields isoserine (p. 541) (B. **40**, 92).

A mixture of a little glycerol aldehyde with glycerol ketone or dihydroxyacetone (see below) is formed by the oxidation of glycerol with dilute nitric acid, bromine or hydrogen peroxide in presence of a little ferrous sulphate (C. 1888, II. 104; B. **33**, 3098). It is known as *glycerose*, and is condensed by sodium hydroxide to *inactive acrose*. This compound is related to dextrose, which can also be formed from each of the two separate compounds above mentioned.

Methyl Glycerol Aldehyde, $CH_3CH(OH).CH(OH)CHO$, is a syrupy body formed, analogously to glycerol aldehyde, from its *acetal*, $CH_3CH(OH)CH(OH)\text{-}CH(OC_2H_5)_2$, the oxidation product of croton aldehyde acetal (B. **35**, 1914).

Pentaglycerol Aldehyde, $CH_3C(CH_2OH)_2CHO$, is prepared by condensing propionaldehyde with two molecules of formaldehyde. *Hexyl Glycerol Aldehyde*, $(CH_3)_2C(OH)CH(OH)CH_2CHO$, is obtained by condensation of *d*-hydroxy-isobutyric aldehyde with acetaldehyde (M. **22**, 443, 527).

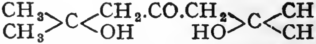
Chloral Aldol, $CCl_3.CH(OH).CH(CHO).CHOH.CH_3$, and *Butyl Chloral Aldol*, $CH_3.CHCl.CCl_2.CH(OH).CH(CHO).CHOH.CH_3$, are thick oils. They result from the condensation of chloral or butyl chloral with paraldehyde and glacial acetic acid (B. **25**, 798).

3. DIHYDROXY-KETONES (OXETONES)

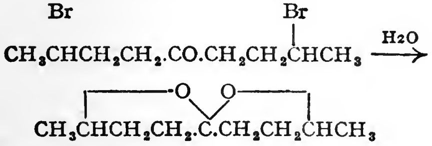
Dihydroxyacetone, Glycerol Ketone [Propane Diolone], $CH_2OH.CO.CH_2OH$, m.p. 68–75°, is prepared from its oxime by the action of bromine (p. 527). It tastes sweet and cooling. Water, alcohol, and acetone dissolve it easily, ether with difficulty. Reduction (p. 527) and the action of the sorbose bacterium (C. 1898, I. 985) convert it into glycerol (see also Glycerose, above). It reduces Fehling's solution in the cold. The *oxime*, $CH_2OH.C{=}N(OH).CH_2OH$, m.p. 84°, is produced from hydroxylamino-tert.-butyl-glycerol by HgO (B. **30**, 3161). *Chloracetyl Carbinol*, $ClCH_2.CO.CH_2OH$, m.p. 74°, is formed from allene (p. 90) and HClO, together with some dichloracetone (C. 1904, I. 576). *Diethoxyacetone*, $(C_2H_5O)CH_2.CO.CH_2(OC_2H_5)$, b.p. 195°, is prepared from *αγ*-diethoxy-acetoacetic ester, and by distillation of calcium ethyl glycollate (B. **28**, R. 295). *Diaminoacetone*, $NH_2CH_2.CO.CH_2NH_2$, is obtained by the reduction of di-isonitroso-acetone (B. **28**, 1519). *2,2-Nitro-bromo-trimethylene Glycol* [*2,2-Nitro-bromo-propane-diol*], $HO.CH_2CBr(NO_2).CH_2OH$, m.p. 106°, is prepared from bromonitromethane and formaldehyde (C. 1899, I. 179).

Homologous Dihydroxyketones.

Trimethyl Triose, $(CH_3)_2C(OH).CH(OH)COCH_3$, b.p.$_{19}$ 109°, is obtained by the oxidation of mesityl oxide, $(CH_3)_2C:CHCOCH_3$ (p. 229), by permanganate, and appears to decompose rapidly into acetone and acetol. *Dihydroxy-dihydro-methyl-heptenone*, $(CH_3)_2C(OH)CH(OH)CH_2CH_2COCH_3$, m.p. 67°, is similarly prepared from methyl heptenone (p. 232) and permanganate (B. **34**, 2979; **35**, 1181). *γδ-Dihydroxy-butyl-methyl Ketone*, $CH_2(OH)CH(OH)CH_2CH_2COCH_3$, b.p.$_{22}$ 190°, results from the splitting up of *α*-acetyl-*δ*-chloro-*γ*-valerol acetone (the condensation product of epichlorhydrin and acetoacetic ester) by means of potassium carbonate (B. **34**, 1981). It is similarly prepared from epichlorhydrin and sodium acetyl acetone (C. 1904, I. 356).

Derivatives of *Triacetone Dialcohol*,  $\begin{matrix}CH_3\\CH_3\end{matrix}\!>\!C\!<\!\begin{matrix}CH_2.CO.CH_2\\OH\qquad\quad HO\end{matrix}\!>\!C\!<\!\begin{matrix}CH_3\\CH_3\end{matrix}$ (which is as yet unknown) are compounds, discussed in connection with phorone (p. 229), such as triacetonamine, triacetone diamine, triacetone hydroxylamine, triacetone dihydroxylamine, their anhydrides and dinitroso-di-isopropyl-acetone. Similar compounds when treated with ammonia, also yield, in part, methyl ethyl ketone p. 224). *Trimethyl Diethyl Ketopiperidine*, $CO<\begin{matrix}CH(CH_3)\text{—}C(CH_3)(C_2H_5)\\CH_2\text{———}C(CH_3)(C_2H_5)\end{matrix}>NH$, m.p. 247°, corresponding with triacetonamine (B. **41**, 777).

The oxetones, discovered by *Fittig*, may be considered as the anhydrides of the γγ-dihydroxyketones. Their constitution is indicated by the formation of dimethyl oxetone by treatment of the addition product of dialkyl acetone with two molcules of HBr with potash solution (*Volhard*, A. **267**, 90):



The oxetones are obtained from the condensation products of the γ-lactones with sodium ethoxide in consequence of the elimination of carbon dioxide (see p. 374).

Oxetone, $C_7H_{12}O_2$, b.p. 159·4°. *Dimethyl Oxetone*, $C_9H_{16}O_2$, b.p. 169·5°, $D_0=0·978$. *Diethyl Oxetone*, $C_{11}H_{20}O_2$, b.p. 209°. These oxetones are mobile liquids, and possess an agreeable odour. They are not very soluble in water, reduce an ammoniacal silver solution, and combine with 2HBr to γ-dibromoketones.

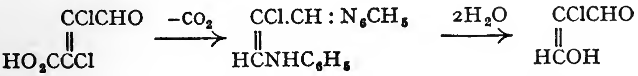
γ-Pyrone, $CO<\begin{matrix}CH=CH\\CH=CH\end{matrix}>O$, may be considered the anhydride of an unsaturated dihydroxyketone.

4. HYDROXY-DIALDEHYDES

Nitromalonic Dialdehyde, $NO_2CH(CHO)_2$, or $HO_2N:C(CHO)_2$, m.p. 50°, is a derivative of the dialdehyde of tartronic or hydroxymalonic acid. Its sodium salt is prepared from mucobromic acid (p. 402) and sodium nitrite (comp. C. 1900, II. 1262). The free aldehyde is obtained from the silver salt by hydrochloric acid, in ethereal solution. In aqueous solution it changes into formic acid and sym.-trinitrobenzene (Vol. II.). It condenses with acetone in alkaline solution to form *p*-nitrophenol, and behaves similarly with a series of other ketones, ketonic acid esters, etc. (C. 1899, II. 609; 1900, II. 560). Hydroxylamine converts nitromalonic aldehyde into *nitro-isoxazole*, $NO_2C\begin{matrix}\diagup CH=N\\ \qquad\quad |\\ \diagdown CH\text{—}O\end{matrix}$, and salts of the unstable *nitromalonic aldehyde dioxime*, $MeO_2N.C(CH:NOH)_2$, which can be converted into *nitromalonic aldoxime nitrile*, $NO_2HC(CN)CH:NOH$, and *fulminuric acid*, $NO_2HC(CN)CONH_2$ (C. 1903, I. 957).

Chloromalonic Dialdehyde, $ClCH(CHO)_2$ or $CHO.CCl:CHOH$, m.p. 144°, with decomposition, and

Bromomalonic Dialdehyde, $BrC_3H_3O_2$, m.p. 140°, with decomposition, are prepared from nitromalonic aldehyde and mucochloric and mucobromic acids. Aniline causes the loss of CO_2 and converts them into dianils of the dialdehydes, which are liberated by hydrolysis:



The two dialdehydes are also formed from ethoxyacroleïn acetal $(C_2H_5O)CH:CH.CH(OC_2H_5)_2$ (see Malonic Dialdehyde, p. 347), by chlorine and bromine. The *enol*-configuration (see above) gives rise to strongly acid bodies giving a reddish-violet coloration with ferric chloride. Their stability towards alkalis is remarkable. Hydrazines give rise to *pyrazoles* (B. **37**, 4638).

5. HYDROXY-ALDEHYDE KETONES

Hydroxypyroracemic Aldehyde, $CHO.CO.CH_2OH$, m.p. 134°, is the simplest hydroxyaldehyde ketone. It is only known in the form of its osazone, and is produced by the interaction of phenylhydrazine and dihydroxyacetone (B. **28**, 1522).

Propanone Trisulphonic Acid, $(SO_3H)_2CHCOCH_2(SO_3H)$, is a derivative of hydroxypyroracemic acid, prepared by the action of fuming sulphuric acid on acetone. It is decomposed by alkalis into methionic and sulphoacetic acid (C. 1902, I. 101).

6. HYDROXY-DIKETONES

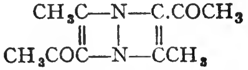
αβ-Diketo-butyl Alcohol, $CH_3CO.COCH_2OH$, is the simplest hypothetical hydroxydiketone. A derivative is *α-Dibromethyl Ketol*, $CH_3CBr_2.CO.CH_2OH$, m.p. 85°, prepared from bromotetrinic acid (p. 544) and bromine.

Derivatives of a body, $(CH_3)_2C(OH)COCOCH_3$, are found among the reaction products of nitrous or nitric acid on mesityl oxide oxime (p. 231).

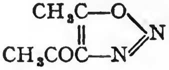
1-*Ethoxyacetyl Acetone*, $(C_2H_5O)CH_2COCH_2COCH_3$, b.p.$_{13}$ 84°, is prepared from ethoxyacetic ester, sodium, and acetone (comp. p. 350) (C. 1907, I. 871).

3-*Aminoacetyl Acetone*, $(CH_3CO)_2CHNH_2$, is formed when isonitroso-acetyl acetone is reduced. Nitrous acid converts it into *Dimethyl Diacetyl Pyrazine* (1), m.p. 99°, and a diazo-anhydride or *furo*[ab]*diazole* (2), of which the connecting oxygen is easily replaceable by NR and S (see Vol. II.; *Pyrro*[ab]*diazoles* and *Thio*[ab]*diazoles*) (A. **325**, 129):

(1)



(2)



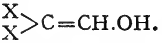
Hydroxymethylene Acetyl Acetone, $(CH_3CO)_2C{=}CHOH$, m.p. 47°, b.p. 199°, which is the *aci*- or *enol*-form of sym.-*Formyl Acetyl Acetone, Formyl Diacetyl Methane*, $(CH_3CO)_2CH.CHO$, is a stronger acid than acetic acid, and soluble in aqueous alkali acetates. It readily absorbs oxygen from the air, and is decomposed by gentle heating with water and HgO into CO_2 and acetyl acetone; *copper salt*, m.p. 214°.

Ethoxymethylene Acetyl Acetone, $(CH_3CO)_2C{=}CH(OC_2H_5)$, b.p.$_{16}$ 141°, is formed by condensation of acetyl acetone with orthoformic ether by acetic anhydride. It decomposes with water into alcohol and the previous substance. It combines with acetyl acetone to form *Methenyl-bis-acetyl Acetone*, $(CH_3CO)_2C{=}CH{-}CH(COCH_3)_2$, m.p. 118°, which is easily changed by ammonia into diacetyl lutidine (Vol. II.), and by abstraction of water into diacetyl *m*-cresol.

Aminomethylene Acetyl Acetone, $(CH_3CO)_2C:CHNH_2$, m.p. 144°, is formed from ethoxymethylene acetyl acetone and ammonia. *Anilinomethylene Acetyl Acetone*, $(CH_3CO)_2C:CHNHC_6H_5$, m.p. 90°, results when diphenyl formamidine, $C_6H_5N:CH.NHC_6H_5$, is heated with acetyl acetone (B. **35**, 2505).

Hydroxymethylene acetyl acetone, as well as the corresponding derivatives of acetoacetic ester and malonic ester, can be considered as being formic acid in which the intra-radical oxygen has been replaced by a carbon atom carrying two negative groups (X):

$O{=}CH.OH$



$$\begin{matrix}X\\X\end{matrix}\!>C{=}CH.OH.$$

Formic Acid. Hydroxymethylene Compounds:

As these bodies are strong monobasic acids, the group $X_2C{=}$ would seem to exert an influence on the carbon atom combined with it, or on the hydroxyl in union with the carbon atom, just as is done by oxygen that is joined with two bonds, but the influence may not be as great as in the latter case. The compounds just described are the first of the complex substances, containing only C, H, and O, which, without carboxyl, still approach the monocarboxylic acids in acidity. Indeed, in some instances they surpass them in this respect (B. **26**, 2731; *L. Claisen*, A. **297**, 1).

7. DIALDEHYDE KETONES

Mesoxalic Dialdehyde, $CHO.CO.CHO$, is formed, together with acetone peroxide, when phorone ozonide (p. 229), $(CH_3)_2C(O_3)CHCOCH(O_3)C(CH_3)_2$, is shaken with water, and the aqueous solution concentrated. It may be in the form of a syrup, the hydrate, solidifying to a glass-like substance, or a loose light yellow powder (a polymerized body), which, in aqueous solution, is strongly reducing in its action. The *diphenylhydrazone*, $CO[CH : NNHC_6H_5]_2$, m.p. 175° with decomposition, is formed by the action of phenylhydrazine, and also from acetone dicarboxylic acid (p. 568) with diazobenzene; the *triphenylhydrazone*, $C_6H_5NHN : C[CH : NNHC_6H_5]_2$, m.p. 166°, may be prepared (B. **38**, 1634).

The *Dioxime, Di-isonitroso-acetone*, $CO[CH : NOH]_2$, m.p. 144°, with decomposition, is formed from acetone dicarboxylic acid and nitric acid; further action of N_2O_3 produces mesoxalic dialdehyde. The *trioxime, trioximidopropane*, $HON : C[CH : NOH]_2$, m.p. 171°, is formed by means of hydroxylamine (B. **38**, 1372).

8. ALDEHYDE DIKETONES

See above, under hydroxymethylene acetyl acetone or aci-*formyl diacetyl methane* (p. 536).

9. TRIKETONES

Related Triketones are obtained from the 1,3-diketones by means of nitroso-dimethyl-aniline, followed by decomposition of the resulting *dimethyl amido-acid* by dilute sulphuric acid (B. **40**, 2714):

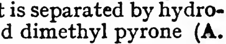
$$(CH_3CO)_2CH_2 \xrightarrow{NOC_6H_4N(CH_3)_2} (CH_3CO)_2C : NC_6H_4N(CH_3)_2 \xrightarrow{H_2O} (CH_3CO)_2CO.$$

These tri-ketones are orange-red oils which form colourless hydrates with water. They are very strongly reducing bodies, and indicate a relationship with animal hairs.

Triketopentane [Pentane-2,3,4-trione], $CH_3CO.CO.COCH_3$, b.p.$_{30}$ 65–70°, is formed by decomposing the reaction product of nitroso-dimethyl-aniline (Vol. II.) and acetyl acetone. It is an orange-yellow oil, which unites with water to form a *colourless* crystalline hydrate, $C_5H_6O_3+H_2O$. The *phenylhydrazone, benzene azo-acetyl acetone*, $C_6H_5NHN : C(COCH_3)_2$, and the *oxime, isonitroso-acetyl acetone*, $HON : C(COCH_3)_2$, m.p. 75°, are prepared from sodium acetyl acetone and diazobenzene salts or nitrous acid (A. **325**, 139, 193). Triketopentane and phenylhydrazine form a *bis-phenylhydrazone*; with semicarbazide a *bis-semicarbazone*, m.p. 221°; with hydrazine hydrate, *dimethyl-hydroxy-pyrazole* (comp. 1,3-diketone, p. 350); with *o*-phenylene diamine, a *quinoxaline*-derivative (comp. 1,2-diketone, p. 348). Alkalis decompose triketopentane into 2 molecules of acetic acid and formaldehyde.

2,3,4-*Triketohexane*, $CH_3CO.CO.COC_2H_5$, b.p.$_{18}$ 70°, is obtained, analogously to triketopentane, from acetyl methyl ethyl ketone, $CH_3COCH_2.COC_2H_5$ (B. **40**, 2728).

2,3,5-*Triketohexane*. The *trioxime*, $CH_3C(NOH)CH_2C(NOH)C(NOH)CH_3$, m.p. 159°, is formed, similarly to succinic dialdoxime from pyrrole (p. 355), and from β-nitroso-$\alpha\alpha_1$-dimethyl-pyrrole and hydroxylamine (C. 1908, I. 1630).

Diacetyl Acetone, 2,4,6-*Triketoheptane*, [2,4,6-Heptane Trione], $CO(CH_2COCH_3)_2$, m.p. 49°, is produced from 2,6-dimethyl pyrone,  $CO\substack{<CH=C(CH_3)> \\ <CH=C(CH_3)>}O$, and concentrated barium hydroxide solution, from which it is separated by hydrochloric acid. It decomposes spontaneously into water and dimethyl pyrone (A. **257**, 276). Ferric chloride produces a deep red colour with it. The *oxime*, m.p. 68°, easily turns into an anhydride (B. **28**, 1817). With sodium and iodomethane it is converted into a *Dimethyl Diacetyl Acetone*, m.p. 87° (C. 1900, II. 625).

Acetonyl Acetyl Acetone, $CH_3COCH_2.CH(COCH_3)_2$, b.p.$_{25}$ 156°, is formed from sodium acetyl acetone and chloracetone (C. 1902, II. 346).

10. DIHYDROXY-MONOCARBOXYLIC ACIDS

The acids of this series bear the same relation to the glycerols that the lactic acids sustain to the glycols, and may also be looked on as being dihydroxy-derivatives of the fatty acids. They may be artificially prepared by means of the general methods used in the production of hydroxacids, and also by the oxidation of unsaturated acids with potassium permanganate (p. 293) (B. **21**, R. 660; A. **283**, 109).

Glyceric Acid, $C_3H_6O_4$, *Dihydroxypropionic Acid*, [Propanediol Acid], is formed: (1) By the careful oxidation of glycerol with nitric acid (method of preparation, B. **9**, 1902, **10**, 267; **15**, 2071); or by oxidizing glycerol with mercuric oxide and barium hydroxide solution (B. **18**, 3357), or with silver chloride and sodium hydroxide (B. **29**, R. 545), or with red lead and nitric acid (C. 1898, I. 26). The calcium salt is decomposed with oxalic acid (B. **24**, R. 653):

$$CH_2(OH).CH(OH).CH_2.OH+O_2=CH_2(OH).CH(OH).CO.OH+H_2O.$$

(2) By the action of silver oxide on β-chlorolactic acid, $CH_2Cl.CH(OH).CO_2H$, and α-chlorohydracrylic acid, $CH_2(OH).CHCl.CO_2H$ (p. 368). (3) By heating glycidic acid with water (p. 539).

Glyceric acid forms a syrup which cannot be crystallized. It is easily soluble in water, alcohol, and acetone. It is optically inactive, but as it contains an asymmetric carbon atom (p. 29), it may be changed to active lævo-rotatory glyceric acid by the fermentation of its ammonium salt, through the agency of *Penicillium glaucum*. *Bacillus ethaceticus*, on the other hand, decomposes inactive glyceric acid so that the lævo-rotatory glyceric acid is destroyed and the dextro-rotatory acid remains (B. **24**, R. 635, 673). This glyceric acid is also formed by reduction of hydroxypyroracemic acid (p. 543), whilst the l-glyceric acid is obtained by the action of milk of lime on glycuronic acid. Further, both forms can be separated by means of brucine (B. **37**, 339; C. 1905, I. 1085, 1089).

Reactions.—When the acid is heated above 140° it decomposes into water, pyroracemic and pyrotartaric acids. When fused with potassium hydroxide it forms acetic and formic acids, and when boiled with it, yields oxalic and lactic acids. Phosphorus iodide converts it into β-iodopropionic acid. Heated with hydrochloric acid, it yields α-chlorohydracrylic acid and $\alpha\beta$-dichloropropionic acid. (See also β-chlorolactic acid (p. 368).)

When glyceric acid is kept, it probably forms a lactide or anhydride. This is sparingly soluble in water, and crystallizes in fine needles.

Salts and Esters.—Its *calcium salt*, $(C_3H_5O_4)_2Ca+2H_2O$, dissolves readily in water; *lead salt*, $(C_3H_5O_4)_2Pb$, is not very soluble in water; *ethyl ester* is formed on heating glyceric acid with absolute alcohol. The rotatory power of the optically active glyceric esters increases with the molecular weight (B. **26**, R. 540), and attains its maximum with the butyl ester (B. **27**, R. 137, 138; C. 1897, I. 970).

The *homologues of glyceric acid* (*Dihydroxy-acids with adjacent hydroxyl groups*) have been obtained (1) from the corresponding dibromo-fatty acids; (2) from the corresponding glycidic acids on heating them with water (A. **234**, 197); and (3) by oxidizing the corresponding unsaturated carboxylic acids (p. 293) with potassium permanganate or persulphuric acid, which at the same time occasion stereoisomeric transformation (comp. Dihydroxystearic Acid) (A. **268**, 8 ; **B. 22**, R. 743 ; C. 1903, I. 319).

αβ-Dihydroxybutyric Acid, β-Methyl Glyceric Acid, $CH_3CH(OH)CH(OH)CO_2H$, m.p. 75°, is resolved from the mixture of its optically active components by quinidine. Also, the α-form appears to result from oxycellulose by the action of milk of lime (B. **32**, 2598 ; C. 1904, I. 933). *αβ-Dihydroxyisobutyric Acid, α-Methyl Glyceric Acid*, $CH_2OH.C(CH_3)(OH)CO_2H$, m.p. 100°. *Triglyceric Acid*, m.p. 88°. *Anglyceric Acid*, m.p. 111° (A. **283**, 109). *α-Ethyl Glyceric Acid*, m.p. 99°. *α-Propyl Glyceric Acid*, m.p. 94°. *α-Isopropyl Glyceric Acid*, m.p. 102° (C. 1899, I. 1071). *α-Ethyl β-Methyl Glyceric Acid, Isohexeric Acid*, $CH_3CH(OH)C(C_2H_5)(OH)COOH$, m.p. 145°, is formed from α-ethyl crotonic acid (A. **334**, 68).

αβDihydroxyiso-octylic Acid, $(CH_3)_2CHCH_2CH_2CH(OH)CH(OH)CO_2H$, m.p. 106° (A. **283**, 291).

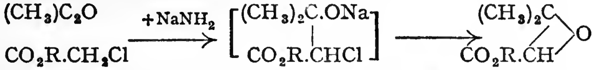
α-Isopropyl β-Isobutyl Glyceric Acid, m.p. 154° (B. **29**, 508).

βγ-Dihydroxybutyric Acid, Butyl Glyceric Acid, $CH_2(OH).CH(OH)CH_2CO_2H$, is a thick oil. The *βγ-dihalogen* and *hydroxy-halogen-butyric acids* corresponding with these, are obtained from vinyl acetic acid (p. 297), or from epihalogen hydrins (p. 532), and hydrocyanic acid ; *γ-Ethoxy-d-hydroxy-butyric Acid* is a syrup ; *ethyl ester*, b.p.$_{13}$ 121° ; *nitrile*, b.p. 245°, is prepared from epiethylin (p. 533) and hydrocyanic acid (C. 1903, II. 106 ; 1905, I. 1586).

γδ-Dihydroxyvaleric Acid, $CH_2(OH)CH(OH)CH_2CH_2CO_2H$, rapidly decomposes into water and forms hydroxylactone.

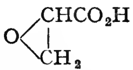
Dihydroxyundecylic Acid, $C_{11}H_{22}(OH)_2O_2$, m.p. 85°, is prepared from undecylenic acid (p. 299). *Dihydroxystearic Acid*, $C_{18}H_{34}(OH)_2O_2$ (see Oleic and Elaïdic Acids, p. 300) (C. 1902, I. 179 ; 1903, I. 319). *Dihydroxybehenic Acid*, $C_{22}H_{42}(OH)_2O_2$, m.p. 127°, is formed from erucic acid, $C_{22}H_{42}O_2$.

Glycidic Acids are formed (1) by the action of alcoholic potassium hydroxide on the addition product of hypochlorous and olefine carboxylic acids (A. **266**, 204) ; (2) by condensation of ketones and α-halogen fatty esters by sodium ethoxide or sodium amide, whereby the glycidic esters are formed :



The acids obtained from these esters easily lose CO_2 and change into aldehydes or ketones (C. 1906, I. 669 ; B. **38**, 699).

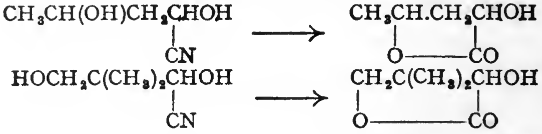
In general, the glycidic acids, like ethylene oxide, form addition products with the halogen acids, water and ammonia, whereby chloro-hydroxy fatty acids, dihydroxy, and amino-hydroxy-fatty acids can be prepared. Many add sodium malonic ester, etc. (C. 1906, II. 421).

Glycidic Acid, *Epihydrinic Acid*,  , is isomeric with pyroracemic acid. It is produced, like epichlorhydrin (p. 532), from α-chlorhydracrylic acid and β-chlorolactic acid by means of alcoholic potassium hydroxide. Glycidic acid, separated from its salts by means of sulphuric acid, is a mobile liquid miscible with water, alcohol, and ether. It is very volatile and has a penetrating odour. The free acid and its salts are not coloured red by iron sulphate solutions (distinction from isomeric pyroracemic acid). It combines with the halogen acids to β-halogen lactic acids, and with water, either on boiling or on standing, it yields glyceric acid. Its *ethyl ester*, m.p. 162°, obtained from the silver salt with ethyl iodide, resembles malonic ester in its odour (B. **21**, 2053).

β-Methyl Glycidic Acid, $CH_3CH.OCHCOOH$, is known in two modifications. The one, m.p. 84°, unites with water to αβ-dihydroxybutyric acid. The other modification is a liquid. *Epihydrin Carboxylic Acid*, $CH_2.O.CHCH_2COOH$, m.p. 225°, is obtained from its nitrile, which results from the action of KCN on epichlorhydrin (p. 532). *α-Methyl Glycidic Acid*, $CH_2.O.C(CH_3)COOH$, consists of shining leaflets. The *ethyl ester*, b.p. 162–164° (B. **21**, 2054). *αβ-Dimethyl Glycidic Acid*, $CH_3CH.O.C(CH_3)COOH$, m.p. 62° (A. **257**, 128).

ββ-Dimethyl Glycidic Acid, $(CH_3)_2C.O.CHCOOH$, is formed as a syrup, from α-chloro-β-hydroxy-isovaleric acid (A. **292**, 282); *ethyl ester*, b.p. 181°, is obtained in good yield from acetone, chloracetic ester and sodium amide (see above) (B. **38**, 707). *ββ-Methyl Ethyl Glycidic Ester*, b.p. 198°; *ββ-Diethyl Glycidic Ester*, b.p. 212°; and *ββ-Trimethyl Glycidic Ester*, b.p.$_{20}$ 81°, etc., are formed according to method 2.

Hydroxylactones are formed from those dihydroxy acids in which the hydroxyl group stands in the γ-position to the carboxyl group. Thus, α-hydroxy-γ-lactones are obtained by hydrolysis of cyanhydrins of the aldols (p. 338):



These hydroxylactones are readily caused by acids to undergo isomeric transformation accompanied by wandering of the OH-group; in the case of *α-hydroxyvalerolactone* (see above), the OH-group apparently migrates first to the β- and finally to the γ-position, forming lævulinic acid (p. 421) (A. **334**, 68; C. 1914, I. 217). On the other hand, the *cyanhydrin* of *β-chloro-diethyl-ketone* (p. 228) and alkali yield salts of *Ethyl Trimethylene Oxide Carboxylic Acid*: $C_2H_5C(COOH).CH_2.CH_2O$, b.p.$_{16}$ 136° (C. 1908, I. 1615).

δ-Hydroxyvalerolactone,  , b.p. 300–301°, results from the action of potassium permanganate on allyl acetic acid (A. **268**, 61). *Hydroxycaprolactone* and *Hydroxyisocaprolactone*, $C_6H_{10}O_3$, are colourless liquids, into which the oxidation products of hydrosorbic acid by means of $KMnO_4$ rapidly pass on liberation from their barium salts (A. **268**, 34). *Hydroxyisoheptolactone*, $(CH_3)_2CH.CH.CH(OH).CH_2.COO$, m.p. 112°. *Hydroxyiso-octolactone*, $(CH_3)_2CH.CH_2.CH.CH(OH)CH_2CO.O$, m.p. 33° (A. **283**, 278, 291).

The following section of the *hydroxy-amino*, *thio-amino*, and *diamino-carboxylic acids* embraces a number of substances which, with the simple amino-acids (pp. 381, 390), commands the greatest interest, as constituting the *decomposition products of the proteïns*—serine, cystine, ornithine, arginine, proline, lysine.

Monoamino-hydroxy-carboxylic Acids.

α-Aminohydracrylic Acid, *α-Amino-β-hydroxy-propionic Acid*, $HO.CH_2CH(NH_2)COOH$, m.p. 246° with decomposition, has been named **serine**, because it was first obtained from sericin (silk-gum). It is also obtained from silk-fibroïn. horn, gelatin, casein, etc., by hydrolysis with dilute acids. It was first synthesized from glycolyl aldehyde (p. 337), ammonia, hydrocyanic acid, and hydrochloric acid (B. **35**, 3794); also, by the following steps: formic ester and hippuric ester were condensed by sodium ethoxide to *formyl hippuric ester*, $CHO.CH(NHCOC_6H_5)COOC_2H_5$ (p. 543), which, on reduction, yields *benzoyl serine ester*, $HOCH_2CH(NHCOC_6H_5)COOC_2H_5$, m.p. 80°; this, on hydrolysis, gives serine (A. **337**, 222). The best synthesis consists in preparing *β-ethoxy-α-amino-propionic acid* $C_2H_5OCH_2.CH(NH_2)COOH$, m.p. 256° with decomposition, from ethoxyacetaldehyde (p. 338), NH_3, HCN, and HCl, and decomposing this with hydrobromic acid (B. **39**, 2644).

Serine forms hard crystals, soluble in 24 parts of water at 20°, but insoluble in alcohol and ether. As an amino-acid it reacts neutral, but forms salts with bases and acids. The taste is sweet, like glycocoll.

Both synthetic and natural serine are optically inactive on account of racemization; resolution can be effected through the *quinine salts* of the p-*nitrobenzoyl*-derivative into d- and l-*serine*, $[\alpha]_{D_{20}} = +6{\cdot}8°$, m.p. 228° with decomposition, soluble in 3–4 parts of water. d-Serine tastes sweeter than l-serine (B. **38**, 2942)

Serine Methyl Ester, a syrup, loses alcohol spontaneously and passes into a di-aci-piperazine (p. 391):

$$CH_2OH.CH<\begin{smallmatrix}NH.CO\\CO.NH\end{smallmatrix}>CHCH_2OH.$$

of which the l-form $[\alpha]_{D_{25}} = -67{\cdot}46^\circ$ appears to be identical with a decomposition product of silk-fibroïn.

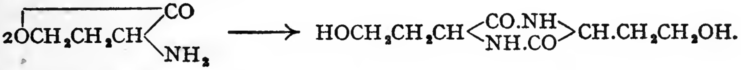
Nitrous acid converts serine into glyceric acid. PCl_5 changes serine ester into *β-chloro-α-amino-propionic acid*, which, on reduction, yields alanine; l-serine gives d-alanine (p. 388).

β-Naphthaline Sulphoserine, m.p. 214°. *Serine β-Phenyl Cyanate*, m.p. 169°.

β-Amino-lactic Acid, α-Hydroxy-β-amino-propionic Acid, **Isoserine**, $H_2NCH_2\text{-}CH(OH)COOH$, m.p. 248° with decomposition, is prepared from β-chlorolactic acid (p. 368) or from glycidic acid (p. 539), and NH_3; from αβ-diaminopropionic acid, hydrochloride, and silver nitrite (B. **37**, 336, 343, 1278); also by reduction of the addition product of acrylic acid and nitrous acid (C. 1903, II. 343); *Isoserine ethyl ester*, m.p. 78°; *methyl ester*, a syrup, passes easily into *isoseryl isoserine ester*, and dipeptide. Isoserine ester hydrochloride yields glyceric ester with sodium nitrite. Reduction produces β-alanine (p. 393) (B. **37**, 1277; **38**, 4171).

α-Amino-β-hydroxy-butyric Acid, $CH_3CH(OH).CH(NH_2)COOH$, m.p. 230° with decomposition, is obtained by reduction of the addition product of crotonic acid and nitrous acid. HI and phosphorus yield α-aminobutyric acid (C. 1903, II. 554).

α-Amino-γ-hydroxy-butyric Acid, $HOCH_2.CH_2CH(NH_2)COOH$, m.p. 207° (indefinite), is obtained by the decomposition of β-hydroxy-ethyl-phthalimido-malonic mono-ester lactone, a product of ethylene bromide and sodium phthalimidomalonic ester (C. 1908, II. 683). The hydrobromide of the *lactone* (formula, see below) is obtained by heating together hydrobromic acid and *γ-Phenoxy-α-amino-butyric acid*, m.p. 233° with decomposition. This substance is prepared by acting with ammonia on phenoxybromobutyric acid, the result of brominating and then decomposing phenoxyethylmalonic acid. The oily lactone changes spontaneously into *di-β-hydroxyethyl diketopiperazine*, m.p. 192° (B. **40**, 106):



α-Amino-γ-hydroxy-valeric Acid, $CH_3CH(OH)CH_2CH(NH_2)COOH$, m.p. 213° with decomposition, is prepared from aldol, NH_3, HCN, and HCl. Like the previous substance, it readily passes into the *aminolactone*, b.p.$_{13}$ 124°, which spontaneously changes into the *dipeptide anhydride*, m.p. 224°. Reduction with HI yields α-amino-n-valeric acid (B. **35**, 3797).

δ-Amino-γ-hydroxy-valeric Acid, $NH_2CH_2CH(OH)CH_2CH_2COOH$, is formed from alkyl acetic acid dibromide (B. **32**, 2682).

α-Amino-δ-hydroxy-valeric Acid, $HOCH_2.CH_2CH_2CH(NH_2)COOH$, m.p. 224° with decomposition, is prepared from phthalimidobromopropyl malonic ester, $BrCH_2CH_2CH_2C(CO_2R)_2N(CO)_2C_6H_4$ (C. 1905, II. 398).

Monaminothiocarboxylic Acids.

α-Amino-β-thiolactic Acid, **Cysteïne**, $HSCH_2.CH(NH_2)COOH$, is easily oxidized by the air to the *disulphide*. **Cystine**, $HOOC.CH(NH_2)CH_2S.SCH_2CH(NH_2)COOH$, decomposes at 258–261°. The lævo-rotatory form of this substance is obtained from many proteïns, especially from hair, horn, egg-shells. It is the *chief sulphur compound of the proteins*. It occurs also in the crystallites of those suffering from cystinuria (C. 1905, II. 1237). The action of nitrous and hydrochloric acids changes cystine into *α-chlorodithiolactic acid*, $(SCH_2CHCl.COOH)_2$, which yields *β-dithiopropionic acid*, $(SCH_2CH_2COOH)_2$, on reduction. Hydrobromic acid produces *cysteïnic acid*, $SO_3H.CH_2CH(NH_2)COOH$, which loses CO_2 and changes into taurine, $SO_3H.CH_2CH_2NH_2$ (p. 326) (C. 1902, II. 1360).

Cysteïne and cystine are closely connected with serine: (1) when β-chloro-α-amino-propionic acid (above) is heated with $Ba(SH)_2$, it yields first cysteïne and then cystine; (2) the syntheic benzoyl serine ester (p. 540), treated with P_2S_5 gives *benzoyl cysteïne ester*, $HSCH_2CH(NHCOC_2H_5)COOC_2H_5$, m.p. 158°, which on hydrolysis is changed to i-cysteïne and i-cystine (A. **337**, 222; B. **40**, 3717). l-Serine produces the natural lævo-rotatory cystine $[\alpha]_{D_{22}} = -224°$. Cystine forms crystals which dissolve with difficulty in water. *Salts* (C. 1905, II. 220); *dimethyl ester*, is a syrup; *hydrochloride*, m.p. 173°, with decomposition (C. 1905, II. 1237).

α-Thio-β-amino-propionic Acid, **Isocysteïne**, $NH_2CH_2CH(SH)COOH$, *hydrochloride*, m.p. 141° with decomposition, is obtained from β-alanine (p. 393) by gradual transformation of its ureïde, hydrouracil (p. 444)—into bromohydrouracil, then into cyanohydrouracil, and decomposing the latter with hydrochloric acid,

Isocysteïne is oxidized by iodine to **Isocystine**, $[SCH(CH_2NH_2)COOH]_2$, m.p. 155°, with decomposition; and by hydrobromic acid into *Isocysteïne acid*, $HO_3S.CH(CH_2NH_2)COOH$ (B. **38**, 630).

α-Thio-γ-amino-butyric Acid and *γ-Amino-α-butyro-sulphonic Acid*, $NH_2CH_2CH_2CH(SO_3H)COOH$ (B. **41**, 513).

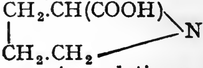
Diaminomonocarboxylic Acids.

Diaminopropionic Acid, $CH_2NH_2.CHNH_2.CO_2H$, is obtained from αβ-dibromopropionic acid by means of aqueous ammonia; also by the decomposition of hippuryl asparaginic acid (p. 554). Optical resolution has been performed by means of its salts with d-camphor sulphonic acid (Vol. II.); and through the quinidine salts of *dibenzoyl diaminopropionic acid* (C. 1906, II. 1119; B. **39**, 2950). The dextro-rotatory compound reacts with 1 molecule of HNO_2 to form isoserine (p. 541), and with 2 molecules of HNO_2 to produce l-glyceric acid. *Diaminopropionic methyl ester* is changed by heat into the ester of diaminopropionyl diaminopropionic ester, one of the dipeptides (B. **38**, 4173).

αβ-Diaminobutyric Acid, $CH_3CH(NH_2).CH(NH_2)COOH$, is formed from αβ-dibromocrotonic acid and ammonia, together with a hydroxyaminobutyric acid (C. 1906, II. 764).

αγ-Diaminobutyric Acid, $NH_2CH_2CH_2CH(NH_2)COOH$, is obtained from phthalimido-ethyl-malonic ester by bromination, hydrolysis of the phthalimido-α-bromobutyric acid formed, treatment with NH_3, and final decomposition; *dibenzoyl* derivative, m.p. 201° (B. **34**, 2900).

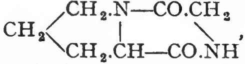
αδ-Diaminovaleric Acid, $NH_2CH_2CH_2CH_2CH(NH_2)COOH$, is synthetically prepared from δ-phthalimido-α-bromovaleric acid, and from the condensation product of phthalimidopropyl bromide with sodium phthalimidomalonic ester (C. 1903, II. 34). It is the optically inactive form of the dextro-rotatory **Ornithine.** This body is produced, together with urea by the action of barium hydroxide solution, on **Arginine**, *α-Amino-δ-guanidino-valeric Acid*, $NH_2(NH)C.NHCH_2CH_2CH_2CH(NH_2)COOH$, a substance found among the decomposition products of many animal and vegetable proteins (B. **34**, 3236; **38**, 4187). Permanganate converts arginine into γ-guanidinobutyric acid (C. 1902, II. 200). It is prepared synthetically from cyanamide, $CN.NH_2$, and ornithine (B. **34**, 454; C. 1902, I. 300). The *dibenzoyl* derivative of ornithine, **Ornithuric Acid**, m.p. 185°, occurs in the urine of hens when fed with benzoic acid (B. **31**, 3183).

α-Pyrrolidine Carboxylic Acid, **Proline**,  is the *imine* of αδ-diaminovaleric acid. It results when casein, gelatin, and other proteins are treated with hydrochloric acid. It can be synthetically prepared in several ways, more particularly from αδ-dibromovaleric acid and ammonia; and from δ-bromo-α-amino-valeric acid, the decomposition product of bromopropyl phthalimidomalonic ester (C. 1908, II. 680; B. **33**, 1160; **34**, 3071; **37**, 3071; C. 1902, II. 284).

It is connected with the *coca*-alkaloids.

αε-Diaminocaproic Acid, $NH_2CH_2CH_2CH_2CH_2CH(NH_2)COOH$, is prepared synthetically by the reduction of α-hydroximido-γ-cyano-valeric acid by means of sodium and alcohol. This product is the inactive form of the optically active **lysine**, which is formed in the decomposition of casein and other proteins. Pancreatic decomposition converts lysine into pentamethylene diamine (cadaverine,

p. 334); and ornithine into tetramethylene diamine (putresceïne, p. 333) (B. **32**, 3542; C. 1902, I. 985). Permanganate oxidizes lysine into glutaric acid, together with hydrocyanic and oxalic acids (B. **35**, 3401).

Like the simple amino-acids, the hydroxyamino-, thioamino-, and diamino-carboxylic acids are connected with one another and with the mono-amino acids in so far that through their amides they go to form proteïn-like bodies, such as *di-* and *poly-peptides* and *dipeptide anhydrides* (*diazopiperazines*, p. 391). Therefore, in general, similar methods of formation can be employed in both cases: *Diglycl Cystine*, $[NH_2CH_2CONHCH(COOH)CH_2S]_2$, is prepared from bischloracetyl cystine and ammonia; *Leucyl Proline* from bromisocaproyl proline; *anhydride*, m.p. 126–129°. *Prolyl Alanine*, from αδ-dibromo-valeryl-alanine; *anhydride*, m.p. 171-121°. *Prolyl Glycine Anhydride*, , m.p. 183°, is obtained by tryptic digestion of gelatin (comp. B. **37**, 3071, 4575; **38**, 4173; **39**, 2060, etc.).

Dihydroxyolefine Monocarboxylic Acids.

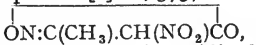
The γ-lactones of these bodies are the tetronic acid and mono-alkyl tetronic acids. These substances can also be looked on as being the *aci*-forms of *β-Keto-γ-lactones*. They are, therefore, considered under the heading of hydroxy-ketone-carboxylic acids (below) according to the principle set down on p. 398.

11, 12. Aldo-hydroxy-carboxylic Acids and Hydroxy-keto-carboxylic Acids.

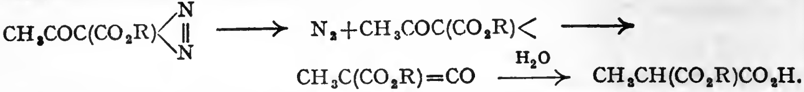
Hydroxypyroracemic Acid, $CH_2OH.CO.COOH$, or *Formyl Hydroxyacetic Acid, Tartronic Acid Semi-Aldehyde*, $CHO.CH(OH)COOH$, is formed when nitrocellulose (collodion cotton) is treated with sodium hydroxide solution. Reduction converts it into *l*-glyceric acid; hydrocyanic and hydrochloric acids produce *l*- and some meso-tartaric acid (C. 1905, I. 1088). *Formyl-* or *Hydroxymethylene Hippuric Ester*, $OCH.CH(NHCOC_6H_5)CO_2R$, or $HOCH : C(NHCOC_6H_5)CO_2R$, m.p. 128° (comp. p. 540), is a derivative of formyl hydroxyacetic acid. *Tribromomethyl Ketol*, $CH_2OH.CO.CBr_3$, decomposes at 174° (see Bromotetronic Acid, p. 544).

The following substances are derived from the *enol-* or *aci*-form of **α-Hydroxyacetoacetic Acid**, $CH_3COCH(OH)COOH$, and **γ-Hydroxyacetoacetic Acid**, $HOCH_2.COCH_2COOH$, both of which are unknown in the simple form.

α-Thioacetoacetic Ester, $S[CH(COCH_3)CO_2C_2H_5]_2$, *keto*-form, m.p. 76°, is prepared by the action of sulphur chloride or thionyl chloride on acetoacetic ester. The solid *keto*-form is converted into the oily *enol-* or *aci*-form by the influence of solvents (alcohol, benzene), or a trace of alkali; soda causes the re-production of the keto-body (B. **39**, 3255). *Benzene-sulphone-thioacetoacetic Ester*, $C_6H_5SO_2.SCH(COCH_3)CO_2C_2H_5$, m.p. 55°, is prepared from α-chloracetoacetic ester and benzene thiosulphonate (J. pr. Ch. [2] **70**, 375).

α-Nitro-methyl-isoxazolone,  $ON:C(CH_3).CH(NO_2)CO$, decomposes at 123°, is formed when isonitroso-methyl-isoxazolone is oxidized by nitric acid (B. **28**, 2093).

α-Amino-acetoacetic Acid, $CH_3CO.CH(NH_2)COOC_2H_5$, is obtained by the reduction of isonitroso-aceto-acetic ester (p. 546) by zinc and sulphuric acid, together with *dimethyl pyrazine dicarboxylic ester* (Vol. II.). Amino-acetoacetic acid reacts with nitrous acid to form *Diazo-acetoacetic Ester Anhydride*, , or , an oil, $b.p._{12}$ 102–104°. Acids and alkalis convert it into acetic and diazo-acetic acids (p. 402). When boiled with water or superheated to above 110°, it breaks down into nitrogen and methyl malonic mono-ester (*L. Wolff*, A. **325**, 129), a decomposition which may be explained as follows (*Schroeter*):



$$\text{CH}_3\text{COC(CO}_2\text{R)}\Big<\begin{array}{l}\text{N}\\ \|\\ \text{N}\end{array} \longrightarrow \text{N}_2+\text{CH}_3\text{COC(CO}_2\text{R)}< \longrightarrow$$
$$\text{CH}_3\text{C(CO}_2\text{R)}{=}\text{CO} \xrightarrow{\text{H}_2\text{O}} \text{CH}_3\text{CH(CO}_2\text{R)CO}_2\text{H}.$$

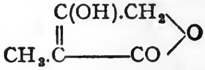
Ammonia or amines convert the diazo-anhydride into *pyrro*[ab]*diazole*; H_2S produces *thio*[ab]*diazole* (Vol. II.). β-Diketones react with it as with aromatic diazo-bodies (Vol. II.), forming azo-compounds, such as hydrazones, which easily condense further to *pyrazoles*.

α-Isonitramine Acetoacetic Acid; sodium salt, $CH_3COCNa(N_2O_2Na)CO_2C_2H_5$ (pp. 397, 416).

Lactones of the γ-Hydroxy-acetoacetic Acids (pp. 420, 543) are tetronic acid and the alkyl tetronic acids. Substances of this class were obtained by *Demarçay* from γ-mono-bromo-substituted mono-alkyl acetoacetic esters by alcoholic potassium hydroxide, and were named by him tetrinic acid, pentinic acid, etc. *Michael* recognized in tetrinic acid a keto-lactone (formula 1). *L. Wolff* examined the parent substance of these compounds and called it tetronic acid, and derived *Demarcay's* acids from it under the names of α-methyl-, α-ethyl tetronic acid, etc. (A. **291**, 226). The keto- and enol-formulæ (I. and II.) are applicable to tetronic acid and α-methyl tetronic acid (tetrinic acid):

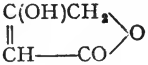
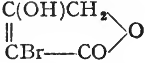
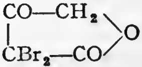
I. 

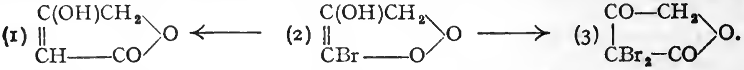
$$\begin{array}{l}\text{CO.CH}_2\\ \quad|\\ \text{CH}_3\text{CH.CO}\end{array}\!\!>\!\text{O}$$

II. 

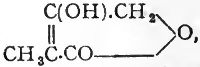
$$\begin{array}{l}\text{C(OH).CH}_2\\ \|\\ \text{CH}_3\text{.C}\text{———CO}\end{array}\!\!>\!\text{O}$$

but *Conrad* and *Gast* favour the hydroxyl formula, through indirect evidence, namely: that they prepared the lactone of γ-hydroxy-dialkyl-acetoacetic acids from dialkyl acetoacetic esters and γ-bromo-dialkyl-acetoacetic ester, and they showed that these true keto-lactones differ throughout in boiling-point and chemical behaviour from tetronic acid and the α-alkyl tetronic acids.

Tetronic Acid,  $\begin{array}{l}\text{C(OH)CH}_2\\ \|\\ \text{CH}\text{——CO}\end{array}\!\!>\!\text{O}$ (1) is prepared from synthetic tetronic ester, by hydrolysis, and elimination of CO_2 (B. **36**, 471); also by reduction by sodium amalgam of *α-Bromotetronic acid,*  $\begin{array}{l}\text{C(OH)CH}_2\\ \|\\ \text{CBr}\text{——CO}\end{array}\!\!>\!\text{O}$ (2) the decomposition product of αγ-dibromacetoacetic ester. *Dibromotetronic acid,*  $\begin{array}{l}\text{CO—CH}_2\\ |\\ \text{CBr}_2\text{—CO}\end{array}\!\!>\!\text{O}$ (3) is obtained from bromotetronic acid and bromine. It slowly decomposes into bromotetronic acid and tribromo-methyl-ketol (p. 543), with elimination of CO_2.

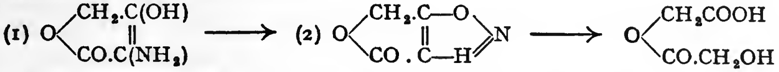


$$(1)\ \begin{array}{l}\text{C(OH)CH}_2\\ \|\\ \text{CH}\text{——CO}\end{array}\!\!>\!\text{O} \longleftarrow (2)\ \begin{array}{l}\text{C(OH)CH}_2\\ \|\\ \text{CBr}\text{——O}\end{array}\!\!>\!\text{O} \longrightarrow (3)\ \begin{array}{l}\text{CO—CH}_2\\ |\\ \text{CBr}_2\text{—CO}\end{array}\!\!>\!\text{O.}$$

Tetrinic Acid, *α-Methyl Tetronic Acid,*  $\begin{array}{l}\text{C(OH).CH}_2\\ \|\\ \text{CH}_3\text{C·CO}\text{———}\end{array}\!\!>\!\text{O}$, m.p. 189°, b.p. 292°, with partial decomposition, results on heating γ-bromo-methyl-acetoacetic ester or by treating it with alcoholic potassium hydroxide. Heated with water to 200°, it breaks down into ethyl ketol (p. 341) and CO_2, and when it is boiled with barium hydroxide it yields glycollic acid and propionic acid. Chromic acid oxidizes it to diacetyl and CO_2 (A. **288**, 1).

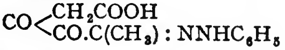
Pentinic Acid, *α-Ethyl Tetronic Acid,* m.p. 128°. **Hexinic Acid,** *α-Propyl Tetronic Acid,* m.p. 126°. **Heptinic Acid,** *α-Isobutyl Tetronic Acid,* m.p. 150°.

It is the tertiary methinic group of the tetronic acid (formula 1, above) and the methylene group in the diketone formula (I., above) that react most actively with other substances: iodine produces directly *iodotetronic acid;* fuming sulphuric gives rise to *sulphotetronic acid.* Nitrous acid gives *oximidotetronic acid, Oximido-ketobutyrolactone,* $(C_4H_2O_3):NOH$, m.p. 136°, with decomposition, which on oxidation yields *Nitrotetronic acid,* $(C_4H_2O_3):NOOH$, m.p. 195°, with decomposition; this substance can also be prepared directly from tetronic acid and nitric acid. Reduction results in the formation of *aminotetronic acid,* from which nitrous acid produces (1) *Diazotetronic anhydride*, m.p. 93°. It is stable towards acids, but with alkalis generates nitrogen and forms (2) *glycolloglycollic Acid*, m.p. 100° (p. 367):



$$\text{(1) } O\left\langle\begin{array}{l}CH_2.C(OH)\\ \quad\ \ \Vert\\ CO.C(NH_2)\end{array}\right. \longrightarrow \text{(2) } O\left\langle\begin{array}{l}CH_2.C{-}O\\ \quad\ \ \Vert\\ CO\,.\,C{-}H\end{array}\right\rangle N \longrightarrow O\left\langle\begin{array}{l}CH_2COOH\\ \\ CO.CH_2OH\end{array}\right.$$

Tetronic acid reacts with diazobenzene salts to form *diketobutyrolactone phenylhydrazone*, $(C_4H_2O_3):NNHC_6H_5$, which is isomerized by alkalis to salts of benzene azotetronic acid. *a-Methyl Tetronic acid* is converted by rupture of the ring into *glycolyl pyroracemic acid phenylhydrazone*,



$$CO\left\langle\begin{array}{l}CH_2COOH\\ CO.C(CH_3):NNHC_6H_5\end{array}\right.$$

by diazobenzene salts.

Aldehydes and ketones unite very readily with two molecules of tetronic acid to form *alkylidene bis-tetronic acids*, $(C_4H_3O_3)_2CRR_1$, substances from which further condensation produces a series of interesting cyclic compounds (see Vol. II.) (A. **312**, 119; **322**, 351).

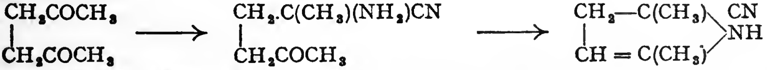
Ethoxyl Acetoacetic Ester, $(C_2H_5O)CH_2COCH_2COOC_2H_5$, or $CH_3.CO.CH(OC_2H_5).CO_2C_2H_5$, b.p.$_{44}$ 105°, is formed by reduction of ethoxyl chloracetoacetic ester, the condensation product of chloracetic ester and sodium (A. **269**, 15).

γ-Methoxyl Dimethyl Acetoacetic Ester, $(CH_3O)CH_2.CO.C(CH_3)_2CO_2C_2H_5$, m.p. 70°, b.p. 241°, is prepared from γ-bromo-dimethyl-acetoacetic ester and sodium methoxide in methyl alcohol (B. **30**, 856).

γ-Acetoxyl a-Acetyl Butyric Ester, $C_2H_3O.OCH_2.CH_2CH(COCH_3)CO_2CH_3$, b.p.$_{12}$ 150–153°, is formed from glycol bromacetin (p. 230) and sodium acetoacetic ester (C. 1904, II. 586).

a-Hydroxylævulinic Acid, $CH_3CO.CH_2CH(OH)CO_2H$, m.p. 103°, and *β-Hydroxylævulinic Acid*, $CH_3COCH(OH)CH_2CO_2H$, an oil, are prepared from the corresponding bromolævulinic acids (A. **264**, 259). Chloral acetone (p. 342) may be considered as being the orthotrichloride of the first of these acids.

a-Amino-a-methyl-lævulinic Acid; the *nitrile* (formula, see below), b.p.$_{17}$ 108°, is formed from acetonyl acetone (p. 351) and ammonium cyanide. It readily loses water and passes into a cyclic imine or *pyrroline* derivative (B. **40**, 2886):

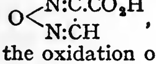


$$\begin{array}{l}CH_2COCH_3\\ |\\ CH_2COCH_3\end{array} \longrightarrow \begin{array}{l}CH_2.C(CH_3)(NH_2)CN\\ |\\ CH_2COCH_3\end{array} \longrightarrow \left.\begin{array}{l}CH_2{-}C(CH_3)\ CN\\ |\\ CH = C(CH_3)\end{array}\right\rangle NH$$

Ketohydroxystearic Acid, $CH_3[CH_2]_5CH(OH)CH_2CH_2CO[CH_2]_7COOH$, m.p. 84°, is obtained from ricinostearolic acid (p. 302). An *isomeric* ketohydroxystearic acid, m.p. 64°, is obtained by oxidizing oleïc acid with permanganate in neutral solution (B. **36**, 2657).

Hydroxy-olefine Ketocarboxylic Acids include *Hydroxymethylene Acetoacetic Ester*, $HOCH:C(COCH_3)CO_2R$, which can also be looked on as being the *aci*-form of *formyl acetoacetic ester* among the aldehydoketone carboxylic acids (below).

13. ALDEHYDOKETONE CARBOXYLIC ACIDS

Glyoxyl Carboxylic Acid, $CHO.CO.CO_2H$, is formed by the oxidation of tartaric acid by chlorine in the presence of ferrous salts; also from dihydroxymaleïc acid (*q.v.*) and ferric sulphate (C. 1902, I. 857, 978). *Uric Acid* may be looked upon as the diureïde of this half-aldehyde of mesoxalic acid. *Di-isonitrosopropionic Acid*, $HON:CH.C:N(OH).CO_2H$, is the dioxime of glyoxyl carboxylic acid. It is obtained from dibromopyroracemic acid. It is known in two modifications, the one m.p. 143°, the other m.p. 172° (B. **25**, 909). *Furazan Carboxylic Acid*,  $O\left\langle\begin{array}{l}N:C.CO_2H\\ N:CH\end{array}\right.$, m.p. 107°, is the anhydride of this dioxime. It results from the oxidation of furazan propionic acid with $KMnO_4$. Sodium hydroxide causes it to rearrange itself into cyanoximido-acetic acid (A. **260**, 79; B. **24**, 1167). *Osazone* of glyoxyl carboxylic acid, $CH(NNHC_6H_5)C(NNHC_6H_5)COOH$, m.p. 223°.

Glyoxyl Propionic Acid, $HCO.CO.CH_2CH_2CO_2H$, results, together with diacetyl, when $\beta\delta$-dibromolævulinic acid is boiled with water. It forms a yellow varnish. It passes into succinic acid upon oxidation. Its *oxime* is *$\gamma\delta$-dioximido-valeric acid,* $HC(:NOH).C(:NOH).CH_2.CH_2.CO_2H$, m.p. 136°. Concentrated sulphuric acid changes it into the anhydride, *Furazan Propionic Acid,* $O\!<\!\begin{smallmatrix}N:C.CH_2CH_2CO_2H\\ N:CH\end{smallmatrix}$, m.p. 86°. Sodium hydroxide converts this acid into *cyanoximidobutyric acid* (p. 568), whilst with potassium permanganate it yields furazan carboxylic acid. In the form of a keto-aldehyde (see pp. 346, 349), glyoxyl propionic acid condenses with ammonia and formaldehyde to a *glyoxaline propionic acid,*  $CH\!\begin{smallmatrix}\nearrow N—CH\\ \quad\ \ \|\\ \searrow NH.CCH_2CH_2CO_2H\end{smallmatrix}$, which is also produced from *histidine,* one of the protein decomposition bodies (C. 1905, II. 830; 1908, II. 606).

Gloxyl Isobutyric Acid, $CHO.CO.C(CH_3)_2COOH$, m.p. 138°, is obtained from the isomeric *Dihydroxyacetyl Dimethyl Acetic Acid Lactone,* $(HO)\overline{CH.CO.C(CH_3)_2COO}$, m.p. 168°, by solution in soda and subsequent precipitation by hydrochloric acid.

The lactone was obtained on treating γ-methoxy-dimethyl-acetoacetic ester with bromine, and then decomposing the monobromosubstitution product with water (B. **30**, 856).

Derivatives of an aldehydo-keto-carboxylic acid, $CHO.CH_2CO.CO_2H$ (or an unsaturated hydroxy-aldehydic acid, $CHO.CH:C(OH)CO_2H$), are probably exemplified by *muco-hydroxy-chloric acid* and *muco-hydroxy-bromic acid* (p. 402) (Am. **9**, 148; 160).

Formyl Acetoacetic Acid, $CHO.CH(COCH_3)COOH$, and in its desmotropic *enol*-forms, $HOCH:C(COCH_3)COOH$, and $CH_3C(OH):C(CHO)CO_2H$, is the hypothetical acid from which may, perhaps, be derived

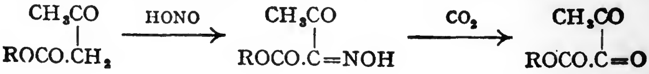
Hydroxymethylene Acetoacetic Ester, $HOCH{=}C\!<\!\begin{smallmatrix}CO_2C_2H_5\\ COCH_3\end{smallmatrix}$, b.p.$_{21}$ 95°, which is formed by the action of water on *Ethoxymethylene Acetoacetic Ester,* $C_2H_5O.CH{=}C\!<\!\begin{smallmatrix}CO_2C_2H_5\\ COCH_3\end{smallmatrix}$, b.p.$_{15}$ 150°. The substances are also obtained from orthoformic ester and acetoacetic ester by heating them with acetic anhydride (B. **26**, 2730). Hydroxymethylene acetoacetic ester is a strong acid (see Hydroxymethylene Acetyl Acetone, p. 536); it is readily soluble in alkali acetates, but is insoluble in water; *copper salt,* m.p. 156°. Ethoxymethylene acetoacetic ester is converted by ammonia into *Aminomethylene Acetoacetic Ester* $(C_6H_8O_3){=}CH.NH_2$, m.p. 55°, and combines with acetoacetic ester to form *Methenyl Bis-acetoacetic Ester,* $(C_6H_8O_3):CH(C_6H_9O_3)$, m.p. 96°. The latter is converted by ammonia into lutidine dicarboxylic ester (Vol. II.); and by sodium ethoxide into m-hydroxyuvitic acid (*L. Claisen,* A. **297**, 14). When alkoxymethylene acetoacetic acid is melted with sodium acetoacetic ester, two dyes of undetermined structure are formed—*xanthophanic acid* and *glaucophanic acid* (B. **39**, 2071).

14. DIKETOCARBOXYLIC ACIDS

Paraffin Diketocarboxylic Acids.

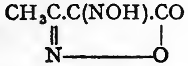
$\alpha\beta$-Diketobutyric Acid, $\alpha\beta$-Dioxybutyric Acid, Acetyl Glyoxylic Acid, $CH_3CO.CO.COOH$. The acid is unknown in the free state, but the *ester* is obtained when acetoacetic ester is acted on by N_2O_3, in acetic anhydride and ether solution. The esters are orange-yellow, mobile liquids (comp. α-Diketones and α-Triketones, p. 348), which combine with water to form colourless crystalline hydrates: *methyl ester,* b.p.$_{12}$ 65–68°, $+H_2O$, m.p. 80°; *ethyl ester,* b.p.$_{18}$ 70°, $+\frac{1}{2}H_2O$, m.p. 148°; *isobutyl ester,* b.p.$_{18}$ 96–100°, $+\frac{1}{2}H_2O$, m.p. 115–120°.

Isonitroso-acetoacetic Ester, $CH_3COC(NOH)CO_2R$, is an intermediate product in the formation of the above esters. The *ethyl ester,* m.p. 56°, b.p.$_{15}$ 155°, can be isolated by treating acetoacetic ester in acetic acid solution with ice-cold sodium nitrite solution; the action of NO_2 converts it into the diketobutyric ester (C. 1905, I. 1591; II. 34):



$$\begin{matrix}CH_3CO\\ |\\ ROCO.CH_2\end{matrix}\xrightarrow{HONO}\begin{matrix}CH_3CO\\ |\\ ROCO.C{=}NOH\end{matrix}\xrightarrow{CO_2}\begin{matrix}CH_3CO\\ |\\ ROCO.C{=}O\end{matrix}$$

Isonitroso-acetoacetic ester is also formed from acetyl malonic ester (p. 564) and nitrous acid. One molecule of hydroxylamine produces *αβ-Di-isonitroso-butyric Ester*, $CH_3C(NOH).C(NOH)CO_2C_2H_5$, m.p. 161°, which is changed by hydrochloric acid into *isonitroso-methyl-isoxazolone* (1), m.p. 159°, one of the *lactazones* (see p. 416), whilst nitric acid causes the formation of a *peroxide* (2), m.p. 92° (B. **28**, 2683; **38**, 926):

(1) 

$$\begin{array}{l} CH_3C.C(NOH).CO \\ \quad \| \qquad\qquad\qquad | \\ \quad N\text{———————}O \end{array}$$

(2) 

$$\begin{array}{l} CH_3C\text{———}C.CO_2H \\ \quad \| \qquad\quad \| \\ \quad N.O.O.N \end{array}$$

β-Phenylhydrazone Acetyl Glyoxyl Ester, $CH_3C(NNHC_6H_5).CO.CO_2C_2H_5$, m.p. 103°, is formed from diketobutyric ester and one molecule of phenylhydrazine in the cold.

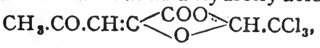
α-Phenylhydrazone Acetyl Glyoxyl Ester, $CH_3CO.C(NNHC_6H_5)CO_2C_2H_5$, m.p. 154°, is prepared from sodium acetoacetic ester and diazo-benzene salts; with phenylhydrazine it forms an *Osazone*, m.p. 209° (A. **247**, 205; C. 1904, II. 588).

βγ-Diketovaleric Acid, *βγ-Dioxovaleric Acid*, $CH_3CO.CO.CH_2CO_2H$, is unknown; but its derivative,

β-Isonitrosolævulinic Acid, $CH_3CO.C(NOH)CH_2CO_2H$, m.p. 119° with decomposition, is formed from acetosuccinic ester (p. 568). When fused, it loses CO_2 and changes into isonitroso-methyl-ethyl-ketone (p. 354).

α-Diketocarboxylic Acids include *stearoxylic acid*, and *behenoxylic acids*, etc., which have already been referred to (p. 304). 9, 12-*Diketostearic Acid*, m.p. 96°, is obtained from ricinostearolic acid (p. 302) C. 1907, I. 916).

β-Diketocarboxylic Acids.

Acetyl Pyroracemic Ester, *Acetone Oxalic Ester*, *αγ-Diketo-* or *αγ-Dioxo-valeric Ester*, $CH_3CO.CH_2CO.CO_2C_2H_5$, is formed from one molecule of acetone, one molecule of oxalic ester, and sodium ethoxide solution (C. 1908, I, 1379). Ferric chloride produces a dark red colour. The free acid liberated from the ester condenses to sym.-hydroxytoluic acid, $CO_2H[1]C_6H_3[3,5](OH)CH_3$ (B. **22**, 3271). Acetone oxalic ester and phenylhydrazine form *Phenyl Pyrazole Carboxylic Ester*, m.p. 133° (A. **278**, 278). With chloral it behaves as an α-hydroxy acid and there results *Acetyl Pyroracemic Chloralide*,  $CH_3.CO.CH{:}C\genfrac{}{}{0pt}{}{<COO>}{<O>}CH.CCl_3$, m.p. 137° (B. **31**, 1305).

Besides acetone, other ketones, such as ethyl methyl ketone, isobutyryl, and butyryl ketone, react with oxalic ester and sodium alcoholate to form *Propionyl Pyroracemic Ester*, $CH_3CH_2CO.CH_2COCO_2C_2H_5$ (?), b.p.$_{0.6}$ 73–78°; *acid*, m.p. 83 (B. **39**, 1333), *Isobutyryl Pyroracemic Ester*, $(CH_3)_2CHCO.CH_2COCO_2C_2H_5$, and *Butyryl Pyroracemic Ester*, $CH_3CH_2CH_2COCH_2COCO_2C_2H_5$ (C. 1902, II. 189; 1903, I. 138) respectively.

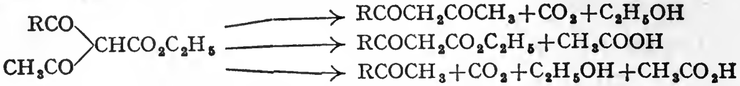
Diacyl Acetic Esters.

The hydrogen in acetoacetic ester can not only be replaced by alkyls, as abundantly shown above, but also by acid radicles (comp. p. 419), by acting with acid chlorides on the sodium compound suspended in ether.

α-Acetyl Acetoacetic Ester, *Diacetyl Acetoacetic Ester*, $(CH_3CO)_2CHCO_2C_2H_5$, b.p.$_{50}$ 123°, is prepared by the action of acetyl chloride as indicated above; by the transformation of the isomeric β-acetoxycrotonic ester by means of K_2CO_3, or by heat (p. 418); by the action of alcohol on the reaction product of $AlCl_3$ and acetyl chloride, $(CH_3CO)_2CH.CCl_2OAlCl_2$ (p. 350) (*Gustavson*, B. **21**, R. 252). The *anilide*, $(CH_3CO)_2CH.CONHC_6H_5$, m.p. 119°, results from the union of diacetyl methane with phenyl isocyanate, and a trace of alkali (B. **37**, 4627; **38**, 22). The diacetoacetic ester, like acetoacetic ester itself, forms *metallic salts*. Water at ordinary temperatures slowly converts it into acetic acid and acetoacetic ester: sodium ethoxide causes the displacement of the acetyl group with the formation of acetic ester and sodium acetoacetic ester. Pyridine and acetyl chloride form an O-*acetate*, $CH_3C(OCOCH_3){:}C(COCH_3)CO_2C_2H_5$, b.p.$_{10}$ 143° (B. **33**, 1245). *Cyanacetyl Acetone*, see Acetyl Acetone (p. 351). *Methyl Diacetoacetic Ester* and *Ethyl Diacetoacetic Ester* are volatile only under educed pressure.

Diacyl acetoacetic ester containing two different acid radicles can be decomposed in three ways (comp. pp. 217, 351, 415). When such an ester is treated with water at 148–150°, there are formed diacyl methane, CO_2, and alcohol;

ammonia or fixed alkali in the cold produces mono-acyl-acetic ester and acetic acid; heated with hydrochloric at 130–140° it breaks down into alkyl methyl ketone, CO_2, acetic acid, and alcohol (C. 1903, I. 225):



$$\begin{matrix} RCO \\ CH_3CO \end{matrix}\!\!>CHCO_2C_2H_5 \begin{matrix} \longrightarrow RCOCH_2COCH_3+CO_2+C_2H_5OH \\ \longrightarrow RCOCH_2CO_2C_2H_5+CH_3COOH \\ \longrightarrow RCOCH_3+CO_2+C_2H_5OH+CH_3CO_2H \end{matrix}$$

Iodo-alkyls react with sodium diacyl acetic ester and form acyl alkyl acetic ester by replacement of the acetyl group (C. 1904, II. 25).

Propionyl Acetoacetic Ester, $C_2H_5COCH(COCH_3)CO_2C_2H_5$, b.p.$_{20}$ 111°; *copper salt*, m.p. 89°. n-*Butyryl Acetoacetic Methyl Ester*, b.p.$_{14}$ 105°. *Isobutyryl Acetoacetic Ester*, b.p.$_{15}$ 114°. *Caproyl Acetoacetic Ester*, b.p.$_{10}$ 136°. *Butyryl Isobutyryl Acetic Ester*, $CH_3CH_2CH_2COCH[COCH(CH_3)_2]CO_2C_2H_5$, b.p.$_{18}$ 125°.

ββ-Diacetopropionic Ester, $(CH_3CO)_2CHCH_2CO_2C_2H_5$, b.p.$_{24}$ 147°, *ββ-Diacetoisobutyric Ester*, $(CH_3CO)_2CHCH(CH_3)CO_2C_2H_3$, b.p.$_{33}$ 150°, *γγ-Diacetobutyric Methyl Ester*, $(CH_3CO)_2CHCH_2CH_2CO_2CH_3$, b.p.$_{24}$ 161°, are formed from sodium acetyl acetone and chloracetic ester, α-bromopropionic ester, and β-bromopropionic ester, respectively. Sodium alcoholate decomposes diacetopropionic ester into acetic ester and lævulinic ester; sodium alcoholate and iodomethane break it down into acetic ester and β-methyl lævulinic ester. Diacetobutyric ester undergoes similar changes (C. 1902, II. 345).

γ-Acetyl Acetoacetic Ester, Triacetic Acid is prepared in the form of its *lactone*, $CH_3C{:}CHCO.CH_2COO$, by heating dehydracetic acid (*q.v.*) with sulphuric acid (B. **34**, R. 857). When heated with acetic anhydride and sodium acetate it is then reconverted into dehydracetic acid (B. **37**, 338; C. 1905, I. 348; 1906, II. 1044).

γ-Acetyl Dimethyl Acetoacetic Methyl Ester, α-Dimethyl Triacetic Ester, $CH_3CO.CH_2.COC(CH_3)_2CO_2CH_3$, is formed, together with isobutyric ester, from dimethyl acetoacetic methyl ester and sodium at 115–125° (B. **31**, 1339).

γ-Acetyl α-Dimethyl Acetoacetic Ester is similarly formed from diethyl acetoacetic ester and sodium ethoxide (B. **33**, 2683).

γ-Diketocarboxylic Acids.

Acetonyl Acetoacetic Ester, αβ-Diacetopropionic Ester, $CH_3COCH_2.CH(COCH_3)CO_2C_2H_5$, is formed from chloracetone and sodium acetoacetic ester. Fuming hydrochloric acid turns it into pyrotritaric ester (B. **17**, 2759).

When heated with water to 160° the ester yields acetonyl acetone (p. 351).

Acetonyl Lævulinic Acid, $CH_3COCH_2CH_2COCH_2.CH_2CO_2H$, m.p. 75°, is formed from furfuracetone (Vol. II.) when heated with hydrochloric acid (B. **32**, 1176).

Unsaturated Diketocarboxylic Acids, *β-Mesityl Oxide Oxalic Acid*, $(CH_3)_2C{:}CH.CO.CH_2.CO.CO_2H$, m.p. 166° with decomposition. Potassium hydroxide liberates it from either its *ethyl ether*, m.p. 59°, b.p.$_{11}$ 143°, or its *methyl ether*, m.p. 67°. On allowing sodium in ether to act on molecular quantities of mesityl oxide and oxalic ester, then acidifying with dilute sulphuric acid and distilling, a mixture of α- and β-mesityl oxide oxalic esters results. It can be separated by means of a sodium carbonate solution, in which the *α-ether* alone is soluble. Ferric chloride turns this a blood red.

α- or aci-*Mesityl Oxide Oxalic Ethyl Ester*, $(CH_3)_2C{:}CHC(OH){:}CHCO_2C_2H_5$, m.p. 21°, gives a blood-red coloration with ferric chloride. Potassium hydroxide solution liberates the corresponding *acid*, m.p. 92 (A. **291**, 111, 137).

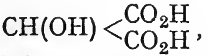
15. MONOHYDROXY-DICARBOXYLIC ACIDS

A. MONOHYDROXY-PARAFFIN DICARBOXYLIC ACIDS, $C_nH_{2n-1}(OH)(CO_2H)_2$.

Numerous saturated monocarboxylic acids are known: thus, the hydroxymalonic acid group corresponds with the malonic acid group, hydroxysuccinic acid group with the ethyl succinic acid group, hydroxyglutaric acid group with the glutaric acid group, etc.

It may be mentioned here that there are many representatives of these acids in which the hydroxyl group occupied the γ-position with reference to the carboxyl group, and these acids, when separated from their salts, readily part with water and become lactones. In general, the alcoholic hydroxyl group is introduced into the dibasic acids, just as it is done in the case of the monobasic acids. The reaction leading to the alkyl paraconic acids (p. 557) is worthy of mention. It is a condensation reaction between aldehydes and succinic acid or mono-alkylic succinic acids (p. 493).

HYDROXYMALONIC ACID GROUP

Tartronic Acid,  $CH(OH)<\begin{matrix}CO_2H\\CO_2H\end{matrix}$, *Hydroxymalonic Acid* [Propanol diacid], m.p. 184° with decomposition, is produced: (1) From glycerol by oxidation with potassium permanganate; (2) from chloro- and bromo-malonic acid by the action of silver oxide or by hydrolysis of their esters with alkalis; (3) from trichlorolactic acid when the latter is digested with alkalis (B. **18,** 754, 2852); (4) from dibromopyroracemic acid when digested with barium hydroxide solution; (5) from mesoxalic acid (p. 562) by the action of sodium amalgam. (6) *Nucleus synthesis:* from glyoxylic acid (p. 400) by the action of HNC and hydrochloric acid, (7) by the spontaneous decomposition of nitrotartaric acid and of dihydroxytartaric acid. (8) It can be conveniently prepared from tartaric acid by allowing it to remain in contact with nitric acid and P_2O_5 (A. **343,** 154).

Its formation from nitrotartaric acid, described in 1854 by *Dessaignes*, has given it the name tartronic acid.

Tartronic acid is easily soluble in water, alcohol, and ether, and crystallizes in large prisms. On melting it is decomposed into carbon dioxide and polyglycollide, $(C_2H_2O_2)x$ (p. 367) (B. **18,** 756).

The *calcium salt*, $C_3H_2O_5Ca$, and *barium salt*, $C_3H_2O_5Ba+2H_2O$, dissolve with difficulty in water, and are obtained as crystalline precipitates.

Ethyl Ester, $CH(OH)(CO_2C_2H_5)_2$, b.p. 222–225° (B. **18,** 2853); *Ethoxyl Malonic Acid*, $C_2H_5O.CH(CO_2H)_2$, m.p. 124°; *ethyl ester* is formed from ethoxyl acetic ester (*q.v.*); *acetate*, $CH_3CO.OCH(CO_2C_2H_5)_2$, b.p.$_{62}$ 158–163° (B. **24,** 2997).

Chloral- and bromal-cyanhydrins (p. 379) and trichlorolactic acid (p. 368) may be looked on as being derivatives of tartronic acid. See also Chloro- and Bromo-malonic ester (p. 489).

Nitromalonic Ester, $NO_2.CH(CO_2C_2H_5)$, b.p.$_{10}$ 127°, and *nitromalonamide*, $NO_2CH(CONH_2)_2$, are prepared from malonic acid and malonamide, respectively, by nitric acid (C. 1901, I. 1196; 1902, I. 1198; 1904, II. 1109). *Nitromalonic Dimethylamide*, $NO_2.CH(CO.NHCH_3)_2$, m.p. 156° (B. **28,** R. 912). *Fulminuric Acid* is a nitromalonic acid derivative (p. 250).

Methyl Nitromalonic Ester, $NO_2C(CH_3)(CO_2C_2H_5)_2$, is formed from the ammonium salt of nitromalonic ester and iodomethane. The higher alkyl nitromalonic esters are obtained by nitrating alkyl malonic esters. Sodium alcoholate converts them into nitro-fatty acid esters (C. 1904, II. 1600).

Aminomalonic Acid, $NH_2CH(CO_2H)_2$, m.p. 109 with decomposition, is formed by the reduction of isonitrosomalonic acid (p. 563); from chloromalonic acid and ammonia (B. **35,** 2550); by alkaline decomposition of uramil (p. 578)

(A. **333**, 77). It forms brilliant prisms. When warmed in aqueous solution it is decomposed into CO_2 and glycine (p. 385). *Methyl Ester Hydrochloride,* m.p. 159° with decomposition, and *Ethyl Ester Hydrochloride,* m.p. 162° with decomposition, are obtained from their acids, and from the isonitrosomalonic esters by reduction. Ammonia produces from them *Aminomalonamide,* m.p. 192° with decomposition (B. **39**, 514). This body is also prepared from chloromalonic ester and alcoholic ammonia at 130°, together with some *Iminomalonamide,* $NH[CH(CONH_2)_2]_2$ (B. **15**, 607). *Aminomalononitrile,* $NH_2.CH(CN)_2$, m.p. 184°, is a product of polymerization of hydrocyanic acid (p. 241) (B. **35**, 1083). *Anilinomalonic Acid,* $C_6H_5NH.CH(CO_2H)_2$, m.p. 121° (C. 1897, II. 568; 1898, I. 829). The esters of this acid are condensed to indoxylic ester (see *Indigo,* Vol. II.). *Phthalimidomalonic Ester,* $C_6H_4(CO)_2N.CH(CO_2C_2H_5)_2$, m.p. 74°, is formed from bromomalonic ester and potassium phthalimide (C. 1903, II. 33).

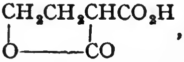
Alkyl Tartronic Acids.—*Methyl Tartronic Acid, Isomalic Acid, a-Hydroxyisosuccinic acid,* $CH_3C(OH)(CO_2H)_2$, is obtained (1) by the action of silver oxide on bromisosuccinic acid; (2) when hydrocyanic acid acts on pyroracemic acid; Pyroracemic ester and hydrocyanic acid produce the *nitrile ester,* $CH_3C(OH)(CN)CO_2C_2H_5$, m.p.$_{19}$ 105°, which is converted on hydrolysis to isomalic acid (C. 1899, I. 1206; B. **39**, 1858); (3) Diacetyl cyanide (p. 409), the *acetate of Methyl Tartrodinitrile,* $CH_3C(OCOCH_3)(CN)_2$, is hydrolyzed by fuming hydrochloric acid to methyl tartronic acid (B. **26**, R. 7; **27**, R. 510). The acid breaks down into CO_2 and lactic acid when it is heated to 140°.

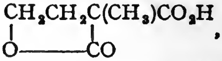
Ethyl Tartronic Acid, $C_2H_5C(OH)(CO_2H)_2$, m.p. 98°, is formed (1) on boiling ethyl chloromalonic ester with barium hydroxide solution (p. 491); (2) from dipropionyl cyanide (p. 409); (3) by the action of ethyl iodide on sodium acetartronic ester (B. **24**, 2999). When heated above its melting point it breaks down into CO_2 and *a*-hydroxybutyric acid. *Propyl Tartronic Acid,* $CH_3CH_2CH_2.C(OH)(CO_2H)_2+H_2O$, m.p. 52–56°, and *Isopropyl Tartronic Acid,* decomposes at 149°, are formed by the hydrolysis of dibutyryl and diisobutyryl dicyanide (p. 409) (B. **28**, R. 295).

a-Aminoisosuccinic Acid, $CH_3.C(NH_2)(COOH)_2$, results when pyroracemic acid is acted on with HNC and alcoholic ammonia (B. **20**, R. 507).

β-Hydroxyisosuccinic Acid, $CH_2OH.CH(CO_2H)_2$, a syrup, is produced by hydrolysis of the reaction product of chloromethyl ether (p. 207) and sodium malonic ester. It decomposes at 113° into H_2O, CO_2, and acrylic acid (C. 1904, II. 641); *ethyl ether,* $C_2H_5OCH_2.CH(CO_2H)_2$, has been obtained from methylene malonic ester (p. 508) by the action of alcoholic potassium hydroxide (B. **23**, R. 194).

γ-Hydroxyalkyl Malonic Acids.—The following γ-hydroxymalonic acids are only known in the form of alkali or alkali earth salts. These are produced when the corresponding γ-lactone carboxylic acids are treated with alkali hydroxides or the hydroxides of the alkali earths. The γ-lactonic acids can easily be obtained from these salts; these salts are produced by treatment with carbonates.

Butyrolactone a-Carboxylic Acid,  $CH_2CH_2CHCO_2H$, O——CO, is prepared from bromethyl malonic acid, $BrCH_2CH_2.CH(CO_2H)_2$, m.p. 117°. This is the hydrobromide addition product of vinaconic acid, the *trimethylene-1,1-dicarboxylic acid,* when it is heated with water; also on digesting the latter with dilute sulphuric acid (A. **227**, 31). Heated to 120°, butyrolactone carboxylic acid breaks down into CO_2 and butyrolactone (p. 373). The *ethyl ester,* b.p.$_{25}$ 175°, is formed by the combination of ethylene oxide and sodium malonic ester, whereby *hydroxyethyl malonic ester* is produced, which immediately loses alcohol to form a lactone. Ammonia converts the lactone ester into *β-Hydroxyethyl Malonamide,* $HOCH_2CH_2.CH(CONH_2)_2$, m.p. 150° (B. **34**, 1976). The *phenyl ether* of *Hydroxyethyl Tartronic Acid,* $C_6H_5O.CH_2.CH_2.CH(COOH)_2$, m.p. 142° (B. **29**, R. 286).

a-Methyl Butyrolactone a-Carboxylic Acid,  $CH_2CH_2C(CH_3)CO_2H$, O——CO, m.p. 98°, results when bromethyl isosuccinic ester, the reaction product of ethylene bromide and sodium isosuccinic ester, is treated with barium hydroxide solution and then acidified (A. **294**, 89).

a-Carbovalerolactonic Acid, γ-Methyl Butyrolactone a-Carboxylic Acid,

$$\begin{array}{l} CH_3CHCH_2CHCO_2H \\ \quad\;\; | \qquad\quad | \\ \quad\;\, O\text{——}CO \end{array}$$

, results when allyl malonic acid is acted on with HBr. It breaks down at 200° into CO_2 and γ-valerolactone (p. 374).

HYDROXYSUCCINIC ACID GROUP

Malic Acid, *Hydroxyethylene Succinic Acid* (*Acidum malicum*), [Butanol diacid],

$$\begin{array}{l} HO.{}^*CHCO_2H \\ \quad\;\; | \\ CH_2CO_2H \end{array}$$

, m.p. 100°. Since malic acid contains an asymmetric carbon atom, it can occur in three modifications: (1) a dextro-rotatory form, (2) a lævo-rotatory form, and (3) an inactive [d+l] variety. This is a compound of equal molecules of the dextro- and lævo-rotatory modifications.

The lævo-variety occurs free or in the form of salts in many plant juices, hence it is frequently spoken of as *ordinary* malic acid. It is found free in unripe apples, in grapes, and in gooseberries, also in mountain ash berries (*Sorbus aucuparia*), in *Berberis vulgaris*, and in the sea buckthorn (or sallow thorn), *Hippophaë rhamnoides* (B. **32**, 3351). It is obtained from the last-named fruits by means of the calcium salts (A. **38**, 257; B. **3**, 966). Calcium hydrogen malate exists in tobacco leaves; potassium hydrogen malate in the leaves and stalks of rhubarb (C. 1902, I. 1399). On malic acid obtained from the *Crassulaceæ*, see B. **31**, 1432.

Historical.—Ordinary malic acid was discovered in 1785 by *Scheele* in unripe gooseberries. *Liebig* ascertained its composition in 1832. *Pasteur*, in 1852, obtained inactive malic acid from inactive aspartic acid, and *Kekulé* (1861) made it from bromosuccinic acid. The dextro-acid was first obtained by *Bremer* in the reduction of dextro-tartaric acid.

Formation of Optically Inactive or (d+l] *Malic Acid*, m.p. 130° (B. **29**, 1698):

1. From the mono-ammonium salt of lævo- and dextro-malic acid.
2. By heating fumaric acid to 150–200° with water.
3. When fumaric or maleïc acid is heated with sodium hydroxide to 100° (B. **18**, 2713).
4. By treating monobromosuccinic acid with silver oxide and water with water alone, with dilute hydrochloric acid, or with dilute sodium hydroxide at 100° (B. **24**, R. 970).
5. By the action of N_2O_3 on inactive aspartic acid.
6. By the reduction of racemic acid with hydriodic acid.
7. When oxalacetic ester is reduced with sodium amalgam in acid solution (B. **24**, 3417; **25**, 2448).
8. By the action of potassium hydroxide on the transposition-product of KNC and β-dichloropropionic ester.
9. By saponifying the esters of chlorethane tricarboxylic acid.
10. When potassium hydroxide acts on γ-trichloro-β-hydroxybutyric acid, $CCl_3CH(OH)CH_2CO_2H$, the reaction-product of glacial acetic acid or pyridine with chloral and malonic acid (B. **25**, 794; **38**, 2733).

The identity of the acids from 1 to 6 has been proved by means of the well-crystallized mono-ammonium salt, $C_4H_5O_5NH_4+H_2O$, of the inactive acid (B. **18**, 1949, 2170).

Formation of the lævo- and dextro- forms: Both acids can be produced by resolution of the inactive malic acid by cinchonine (B. **13**, 351; **18**, R. 537). The dextro-acid has also been obtained by the reduction of ordinary or dextro-tartaric acid with hydriodic acid, and by the action of nitrous acid on dextro-aspartic acid, whereas l-asparagine and l-aspartic acid yield ordinary or l-malic acid (B. **28**, 2772). The two optically active malic acids can be converted into each other by treating chlorosuccinic acids, obtained from them by the action of PCl_5, with moist silver oxide (*Walden*, B. **29**, 133).

Properties.—Malic acid forms deliquescent crystals, which dissolve readily in alcohol, slightly in ether.

Reactions.—(1) When heated to 100° anhydro-acids are formed (B. **32**, 2706); at 140–150° mainly fumaric acid results; when rapidly heated to 180° it decomposes into water, fumaric acid, and maleïc anhydride (pp. 510, 511). Prolonged boiling with aqueous sodium hydroxide converts malic acid partially into fumaric acid (B. **33**, 1452). (2) Oxidation with permanganate or hydrogen peroxide in presence of ferrous salts produces oxaloacetic acid (p. 564). (3) Reduction gives rise to succinic acid. It results from the fermentation of the calcium salt by yeast, of the free acid by *Bacillus aërogenes* (B. **32**, 1915), and when the acid is heated to 130° with hydriodic acid (p. 492). (4) Heating with hydrobromic acid produces bromosuccinic acid; l-malic acid and PCl_5 at ordinary temperatures yield d-chlorosuccinic acid, which, with moist silver oxide changes into d-malic acid (pp. 499, 500). (5) When heated alone or with sulphuric acid or zinc chloride, it is converted into coumalic acid (p. 561). (6) On being heated with phenol and sulphuric acid, coumarin results; it is possible that the half aldehyde of malonic acid $CHO.CH_2.CO_2H$ is first formed, with which the phenol then condenses (B. **27**, 1646).

Salt and esters of i-malic acid: Mono-ammonium Malate, $C_4H_5O_5NH_4+H_2O$ (B. **18**, 1949, 2170). Resolution into the optical components (B. **31**, 528). *i-Malic Diethyl Ester*, $C_2H_3(OH)(CO_2C_2H_5)_2$, b.p. 255° (B. **25**, 2448).

Salts of the lævo-acid, malates: Mono-ammonium salt, $C_4H_5O_5(NH_4)$, when exposed to a temperature of 160–200°, becomes converted into *fumarimide* (A. **239**, 159 note).

Neutral Calcium Malate, $C_4H_4O_5Ca+H_2O$, separates as a crystalline powder on boiling. *Acid* salt, $(C_4H_5O_5)_2Ca+6H_2O$, forms large crystals which are not very soluble in cold water, but are more soluble in hot (B. **19**, R. 679).

l-*Malic Ethers and Esters:* The dialkyl esters are prepared from malic acid, alcohols, and hydrochloric acid. They can be distilled unchanged (Z. phys. Ch. **16**, 494), but when slowly heated pass into fumaric esters (B. **18**, 1952). Reaction with PCl_5 and PBr_5 in chloroform changes them into d-chloro- and d-bromosuccinic esters (p. 499). Attempts to prepare malic esters by means of the silver salt of the acid result in the partial substitution of the hydroxyl hydrogen by the alcoholic radical (C. 1899, I. 779).

The optical rotatory power of many of these esters has been determined; they are lævo-rotatory (B. **28**, R. 725; **29**, R. 164, C. 1897, I. 88):

l-Malic Methyl Ester	$b.p._{12}$ 122°;	$[\alpha]_D = -6.88$,	$[M]_D = -11{\cdot}15$
l-Malic Ethyl Ester	,, 129°;	$[\alpha]_D = -10.64$,	$[M]_D = -20{\cdot}22$
l-Malic n-Propyl Ester	,, 150°;	$[\alpha]_D = -11.60$,	$[M]_D = -25{\cdot}29$
l-Malic n-Butyl Ester	,, 170°;	$[\alpha]_D = -10.72$,	$[M]_D = -26{\cdot}38$

Triethyl Ester, $C_2H_5O.C_2H_3(CO_2C_2H_5)_2$, $b.p._{15}$ 119° (B. **13**, 1394).

Acetyl Malic Acid, $CH_3CO.OC_2H_3(CO_2H)_2$, m.p. 132°.

Acetyl Malic Dimethyl Ester, $CH_3CO.OC_2H_3(CO_2CH_3)_2$, when carefully distilled at the ordinary temperature, yields fumaric dimethyl ester. *Acetyl Malic Anhydride*, $CH_3CO.OC_2H_3(C_2O_3)$, m.p. 54°, $b.p._{14}$ 161°, decomposes when distilled at the ordinary temperature into maleïc anhydride and acetic acid (A. **254**, 166).

Acetyl-l-malic Methyl Ester, b.p.$_{12}$ 132°; $[\alpha]_D = -22{\cdot}86$, $[M]_D = -46{\cdot}64$.
Acetyl-l-malic Ethyl Ester, b.p.$_{12}$ 141°; $[\alpha]_D = -22{\cdot}60$, $[M]_D = -52{\cdot}43$.
Propionyl-l-malic Methyl Ester, b.p.$_{12}$ 142°; $[\alpha]_D = -23{\cdot}08$, $[M]_D = -50{\cdot}31$.

On the *homologous series of acyl l-malic ethyl esters* and their molecular rotations (Z. phys. Ch. **36**, 129).

Nitromalic Ester, $NO_2.OCH(CO_2R)CH_2CO_2R$; *methyl ester*, m.p. 25° $[\alpha]^{20}_D$ —33·01°, and *ethyl ester*, b.p. 148–151° $[\alpha]^{13}_D$—31·24°, are prepared from the l-malic esters and nitrosulphuric acid (B. **35**, 4363).

Amides of the malic acids. α- and *β-Malic Mono-amides*, $NH_2CO.CH(OH)CH_2$-COOH and HOOC.CH(OH)CH_2.$CONH_2$, and their esters are formed from the malic esters and alcoholic ammonia; from malonamide by partial hydrolysis; also, from bromosuccinic acid and ammonia, a reaction which may result in this amide, partially or wholly in place of the expected aspartic acid (B. **41**, 841). *Malamide*, $HO.C_2H_3(CONH_2)_2$, is prepared from the monoamidomalic ester and from the malic ester by the action of ammonia (C. 1900, II. 1009).

Thiomalic Acid, $HOOC.CH_2CH(SH)COOH$, m.p. 150°, is formed by the action of ammonia on *Xanthosuccinic Acid*, $HOOC.CH_2CH(SCSOC_2H_5)COOH$, m.p. 149°, which in turn is prepared from bromosuccinic acid and potassium xanthoganate (A. **339**, 369; B. **38**, 2687).

Sulphosuccinic Acid, $SO_3H.C_2H_3(COOH)_2$, is prepared from succinic acid and SO_3 (A. **175**, 20).

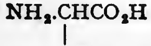
AMINOSUCCINIC ACIDS

Aspartic acid bears the same relation to malic and succinic acids as glycocoll bears to glycollic acid and acetic acid; hence, it may be called aminosuccinic acid:

$NH_2.CH_2CO_2H$
Glycocoll.

$HO.CH_2CO_2H$
Glycollic Acid.

$CH_3.CO_2H$
Acetic Acid.



$$\begin{array}{l} NH_2.CHCO_2H \\ \quad | \\ \quad CH_2CO_2H \end{array}$$

Aminosuccinic Acid.

$$\begin{array}{l} HO.CHCO_2H \\ \quad | \\ \quad CH_2CO_2H \end{array}$$

Malic Acid.

$$\begin{array}{l} CH_2.CO_2H \\ | \\ CH_2.CO_2H \end{array}$$

Succinic Acid.

Aminosuccinic acid contains an asymmetric carbon atom, so that like malic acid, it appears in three modifications. The l-aminosuccinic acid or lævo-aspartic acid is the most important of these. See also d- and l-chlorosuccinic acid (p. 499) and d- and l-malic acid (p. 551, etc.).

Inactive [d+l] Aspartic Acid, *Asparacemic Acid*, $C_2H_3(NH_2)(CO_2H)_2$, is produced:

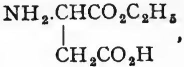
(1) By the union of l- and d-aspartic acids.
(2) On heating active aspartic acid (*a*) with water, (*b*) with alcoholic ammonia to 140–150°, or (*c*) with hydrochloric acid to 170–180° (B. **19**, 1694).
(3) When fumarimide (p. 522) is boiled with hydrochloric acid.
(4) On heating fumaric and maleïc acids with ammonia (B. **20**, R. 557; **21**, R. 644).
(5) By evaporating a solution of hydroxylamine fumarate (B. **29**, 1478).
(6) By reducing oximidosuccinic ester with sodium amalgam (B. **21**, R. 351).

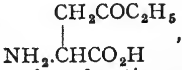
Benzoyl Asparacemic Acid is resolved into its optical components by means of brucine (B. **32**, 2461).

Like glycocoll, it combines with alkalis and acids yielding salts.

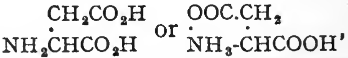
Nitrous acid changes it into inactive malic acid.

[d+l] *Aspartic Diethyl Ester*, $NH_2.C_2H_3(CO_2C_2H_5)_2$, b.p.$_{25}$ 150–154°, is produced on heating fumaric and maleïc esters with alcoholic ammonia (B. **21**, R. 86).

a-Aspartic Mono-ethyl Ester,  $\begin{array}{l}NH_2.CHCO_2C_2H_5\\ \vert\\ CH_2CO_2H\end{array}$, m.p. 165° with decomposition, is formed by the reduction of *a*-oximidosuccinic monethyl ester and the oxime of oxalacetic diethyl ester. Ammonia converts it into *inactive a*-asparagine (constitution, comp. p. 555).

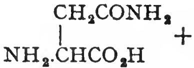
β-Aspartic Mono-Ethyl Ester,  $\begin{array}{l}CH_2COC_2H_5\\ \vert\\ NH_2.CHCO_2H\end{array}$, m.p. 200° with decomposition, is also obtained from the oxime of oxalacetic ester by reduction with sodium amalgam. A partial saponification occurs at the same time. Ammonia converts it into the two *optically active asparagines,* which are therefore β-aminosuccinamic acids.

Phenyl Aspartic Acid, $C_6H_5NH.CH(CO_2H(CH_2CO_2H$, m.p. 131°, is formed by the action of bromosuccinic acid on aniline. *Phenyl Asparaginanil,* $C_6H_5NHC_2H_3C_2O_2.NC_6H_5$, m.p. 210°, results on adding aniline to maleïnanil (A. **239**, 137).

l-Aspartic Acid,  $\begin{array}{l}CH_2CO_2H\\ NH_2CHCO_2H\end{array}$ or $\begin{array}{l}OOC.CH_2\\ NH_3\text{-}CHCOOH\end{array}$, occurs in the vinasse obtained from the beet root, and is procured from proteins in various reactions. It is obtained by the splitting of [d+l] aspartic acid (see above), and from l-asparagine by boiling it with alkalis and acids (B. **17**, 2929).

It crystallizes in small rhombic leaflets or prisms, and is not very soluble in water. Nitric acid converts it into ordinary l-malic acid (B. **28**, 2769). l-Aspartic acid is lævo-rotatory in alkaline solutions, and dextro-rotatory in acids; dextro in aqueous solution at low temperatures, and lævo at higher temperatures. This behaviour may be due to dissociation of cyclic ammonium salts (above) (B. **30**, 294). *Diethyl Ester,* $b.p._{11}$ 126°, is formed from aspartic acid or asparagines by alcohol and hydrochloric acid (B. **34**, 452; **37**, 4599); *dimethyl ester,* $b.p._{15}$ 120° (B. **40**, 2058).

d-Aspartic Acid results when d-asparagine is boiled with dilute hydrochloric acid (B. **19**, 1694) and from l-chlorosuccinic acid (p. 499).

l- and d-Asparagine,  $\begin{array}{l}CH_2CONH_2\\ \vert\\ NH_2.CHCO_2H\end{array}+H_2O$, are the monamides of the two optically active aspartic acids, and are isomeric with malamide (p. 553). Crystallographically, they are identical as regards the hemihedral surfaces (C. 1897, II. 1108).

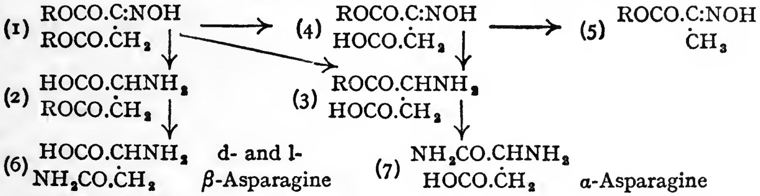
Historical.—As early as 1805 *Vauquelin* and *Robiquet* discovered the lævo-asparagine in asparagus. *Liebig,* in 1833, established its true composition. *Kolbe* (1862) was the first to regard it as the amide of aminosuccinic acid. *Piutti* (1886) discovered dextro-asparagine in the sprouts of vetches, in which it occurs together with much lævo-asparagine.

Lævo-asparagine is found in many plants, chiefly in their seeds; in asparagus (*Asparagus officinalis*), in beet-root, in peas, in beans, and in vetch sprouts, from which it is obtained on a large scale, and also in wheat. The lævo- and dextro-asparagines not only occur together in the sprouts of vetches, but they are found together if asparaginimide, produced from bromosuccinic ester, is heated to 100° with ammonia; or by the action of alcoholic ammonia on β-aspartic ester (B. **20**, R. 510; B. **22**, R. 243). A mixture of the two naturally occurring asparagines has been produced by heating maleïc anhydride to 110° with alcoholic ammonia (B. **29**, 2070).

Both optically active asparagines crystallize in rhombic, right and left hemihedral crystals, which dissolve slowly in hot water, in alcohol and ether, but they are not easily soluble. It is not possible for them to combine in aqueous solution to an optically inactive asparagine. It is remarkable that the dextro-asparagine has a sweet taste, whilst the lævo-form possesses a disagreeable and cooling taste. *Pasteur* assumes that the nerve substance dealing with taste behaves towards the two asparagines like an optically active body, and hence reacts differently with each.

Similar differences of taste are observed with d- and l-valine (p. 389), d- and l-leucine (p. 390), and d- and l-serine (p. 540).

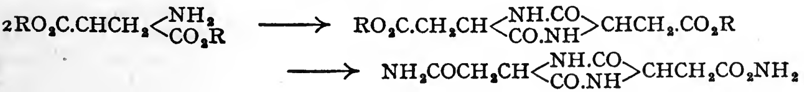
Constitution of the Asparagines.—When the oxime of oxalacetic ester (1) (below) is reduced with sodium amalgam, either α- or β-ethyl aminosuccinic acid (2 and 3) is formed with a partial saponification, depending upon the conditions of the reaction. The constitution of the α-acid, m.p. 165°, follows from its formation by the reduction of the two probable spacial isomeric oximidosuccinic ethyl ester acids (4), which split off CO_2 and yield α-oximidopropionic acid (5) (p. 410). Hence, it may be inferred that the acid melting with decomposition at 200° contains the amino group in the β-position with reference to the carboxethyl group (B. **22**, R. 241). Ammonia converts both acids into their corresponding amino-acids. We obtain inactive α-asparagine (6) from the α-acid, and from the β-acid a mixture of the two optically active β-asparagines (7) results :



$$\begin{tikzcd}
(1)\ \begin{matrix}\mathrm{ROCO.\dot{C}{:}NOH}\\ \mathrm{ROCO.\dot{C}H_2}\end{matrix} \arrow[r] \arrow[d] \arrow[dr] & (4)\ \begin{matrix}\mathrm{ROCO.\dot{C}{:}NOH}\\ \mathrm{HOCO.\dot{C}H_2}\end{matrix} \arrow[r] \arrow[d] & (5)\ \begin{matrix}\mathrm{ROCO.\dot{C}{:}NOH}\\ \mathrm{\dot{C}H_3}\end{matrix} \\
(2)\ \begin{matrix}\mathrm{HOCO.CHNH_2}\\ \mathrm{ROCO.\dot{C}H_2}\end{matrix} \arrow[d] & (3)\ \begin{matrix}\mathrm{ROCO.CHNH_2}\\ \mathrm{HOCO.\dot{C}H_2}\end{matrix} \arrow[d] & \\
(6)\ \begin{matrix}\mathrm{HOCO.CHNH_2}\\ \mathrm{NH_2CO.\dot{C}H_2}\end{matrix}\quad \begin{matrix}\text{d- and l-}\\ \beta\text{-Asparagine}\end{matrix} & (7)\ \begin{matrix}\mathrm{NH_2CO.CHNH_2}\\ \mathrm{HOCO.\dot{C}H_2}\end{matrix}\quad \alpha\text{-Asparagine} &
\end{tikzcd}$$

[d+l]-α-Asparagine, *Isoasparagine,* $HO_2C.CH_2CH(NH_2)CONH_2$, decomposes at 214°, is formed from asparagine imide, aspartic dimethyl ester, and α-aspartic mono-ethyl ester by the action of concentrated ammonia; also, from the potassium salt of aminofumaric monoamide (p. 566) and aluminium amalgam (C. 1897, I. 364).

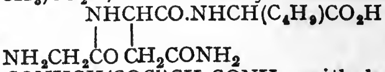
Asparagine Diamide, $NH_2CO.CH(NH_2)CH_2CONH_2$, m.p. 131°, is prepared from aspartic ester and fluid ammonia. It is very soluble in water, and is easily decomposed. *Asparagine Imide, Di-aci-piperazine Diacetamide,* $(C_4H_6ON_2)_2$ (formula, see below), decomposes at 250°, is formed at the same time as asparagine diamide (above). It forms needles, and is with difficulty soluble in water. It is also prepared from bromosuccinic ester and ammonia; and from *Di-aci-piperazine Diacetic Ester* (formula, see below); *methyl ester,* m.p. 248°, *ethyl ester,* m.p. 180–185°, by the same reagent. The latter ester is also obtained when aspartic ester is heated (B. **37,** 4599; **40,** 2059):



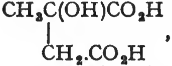
$$2RO_2C.CHCH_2{<}{\substack{NH_2\\ CO_2R}} \longrightarrow RO_2C.CH_2CH{<}{\substack{NH.CO\\ CO.NH}}{>}CHCH_2.CO_2R$$
$$\longrightarrow NH_2COCH_2CH{<}{\substack{NH.CO\\ CO.NH}}{>}CHCH_2CO_2NH_2$$

Hydrolysis of the ester or amide results in the formation of di-aci-piperazine diacetic acid, and also the dipeptide.

Aspartyl Aspartic Acid, $HOOC.CH_2CH(CO_2H)NHCOCH(NH_2)CH_2CO_2H$. The *di-* and *tri-peptides* of the aspartic series are prepared in the same way as the peptides of the simple amino-acids (p. 391, etc.), and serine, cystine, etc. (pp. 540, 541), *e.g. Glycyl Aspartic Anhydride,* $\overline{NHCH_2CONHCH(C}O)CH_2.COOH$, from chloracetyl aspartic ester; *Leucyl Asparagine,* $C_4H_9.CH(NH_2)CONHCH(CO_2H)CH_2$-

$CONH_2$, from bromisocaproyl asparagine; *Aspartyl Dialanine*, $HO_2CCH(CH_3)NHCOCH_2CH(NH_2)CONHCH(CH_3)CO_2H$, from fumaryl dialanine and ammonia; *Glycyl Aspartyl Leucine*,  $\begin{array}{l} \qquad\quad NHCHCO.NHCH(C_4H_9)CO_2H \\ \qquad\quad |\quad\ | \\ NH_2CH_2CO\ CH_2CONH_2 \end{array}$ from *chloracetyl aspartyl chloride*, $ClCH_2CONHCH(COCl)CH_2CONH_2$, with leucine ester and ammonia (B. **37**, 4585; **40**, 2048). *Hippuryl Aspartic Acid*, $C_6H_5CO.NHCH_2CONHCH(CO_2H)CH_2CO_2H$, is prepared from hippurazide (p. 388, Vol. II.), and aspartic acid, and yields a diazide, which, reacting with aspartic ester, gives rise to *hippuryl aspartyl bis-aspartic ester*, and still more complex chain compounds (J. pr. Ch. **70**, 158).

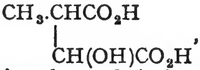
Malic Acid Homologues are formed: by the addition of hydrocyanic acid to β-ketonic esters; by the addition of HClO to alkyl malic acids and subsequent reduction; and by the reduction of alkyl oxalacetic esters.

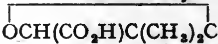
α-Hydroxypyrotartaric Acid, Citramalic Acid, α-Methyl Malic Acid,  $\begin{array}{l} CH_3C(OH)CO_2H \\ | \\ CH_2.CO_2H \end{array}$, m.p. 119°, is produced (1) in the oxidation of isovaleric acid (p. 260) with nitric acid; (2) from acetoacetic ester by means of HNC and HCl; (3) by the reduction of chlorocitramalic acid, the addition product resulting from the union of HClO with citraconic acid; (4) from methyl asparagine and nitric acid. It breaks down at about 200° into water and citraconic anhydride (B. **25**, 196).

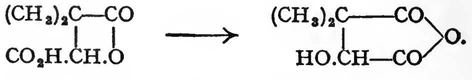
Citramalic acid is resolved into its optical components by means of brucine (B. **32**, 712). *α-Methyl Malic Nitrile Ester, Acetoacetic Ester Cyanhydrin*, $CH_3C(OH)(CN)CH_2CO_2C_2H_5$, m.p. 8·5°, b.p.$_{16}$ 127° (B. **39**, 1858).

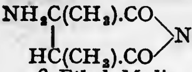
α-Aminopyrotartaric Acid, [d+l]-*Homoaspartic Acid*, $HO_2C.CH_2C(CH_3)(NH_2)CO_2H$, m.p. 166°. Its diamide is formed from itaconic, citraconic, and mesaconic esters by the action of ammonia (B. **27**, R. 121). The acid is resolved into its d- and l- forms by crystallization. *Methyl Asparagine*, $HO_2C.CH_2C(CH_3)(NH_2)CONH_2$ (?), m.p. 255° with decomposition, is formed from citraconic acid and ammonia (C. 1898, II. 762). *α-Anilinopyrotartaric Acid*, $HO_2C.CH_2C(CH_3)(NHC_6H_5)CO_2H$, m.p. 135°, results from the hydrolysis of *α-anilinopyrotartaric monoester nitrile*, an oil, which is formed from acetoacetic ester cyanhydrin and aniline; also, from acetoacetic ester anil and hydrocyanic acid. *Ester Amide*, m.p. 119°, is formed from the nitrile and sulphuric acid in the cold; it is easily converted into the *imide*, m.p. 168° (B. **35**, 2078).

The anilinopyrotartaric acid when heated yields α-anilinopyrotartaric anil and citraconic anil (A. **261**, 138).

β-Methyl Malic Acid,  $\begin{array}{l} CH_3.CHCO_2H \\ | \\ CH(OH)CO_2H \end{array}$, is a colourless syrup, readily soluble in water, in alcohol, and in ether. It is formed when methyl oxalacetic ester is reduced with sodium amalgam, and in an active l- form from a citraconic acid solution by the action of a mould (B. **27**, R. 470). Mesaconic acid and citraconic anhydride (B. **25**, 196, 1484) are produced when it is heated.

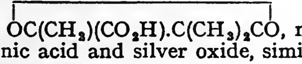
ββ-Dimethyl Malic Acid [2,2-Dimethyl-3-butanol diacid], $CO_2H.CH(OH).C(CH_3)_2.CO_2H$, m.p. 129°, is obtained by the action of alkalis or hydrochloric acid on the lactone. *ββ-Dimethyl Malic Lactone*,  $\overline{O}CH(CO_2H)C(CH_3)_2\overline{CO}$, m.p. 46°, + *aq.*, m.p. 54°, is formed from monobromo-as.-dimethyl-succinic acid and silver oxide. It was the *first β-lactone of the fatty acid series* known (v. *Baeyer* and *Villiger*, B. **30**, 1954). When distilled under reduced pressure it is transformed into the *anhydride*, b.p.$_{18}$ 145–150° (B. **33**, 3270):



αβ-Dimethyl Malic Acid, $CH_3C(OH)(CO_2H)CH(CH_3)CO_2H$, m.p. 143°, is prepared from α-methyl acetoacetic ester cyanhydrin. During distillation it is converted into pyrocinchonic anhydride (p. 518). This, when heated with alcoholic ammonia, is converted into *Amino-dimethyl-succinic Imide*,  $\begin{array}{l}\mathrm{NH_2C(CH_3).CO}\\ \quad|\qquad\qquad\quad\;>\mathrm{NH}\\ \mathrm{HC(CH_3).CO}\end{array}$, m.p. 168° (B. **33**, 1410).

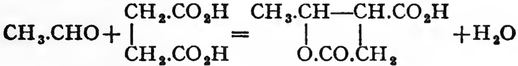
β-Ethyl Malic Acid, $C_2H_5.CH(CO_2H)CH(OH)CO_2H$, m.p. 87° with decomposition. Its *orthotrichloride, a-Ethyl β-Hydroxy-γ-trichlorobutyric Acid*, $C_2H_5CH(CO_2H)CH(OH)CCl_3$, m.p. 137°, is formed from chloral, ethyl malonic acid, and pyridine. When heated with potassium hydroxide it is changed into malic acid, which on heating decomposes into water and ethyl maleïc acid (p. 518) (B. **38**, 2733).

aβ-Methyl Ethyl Malic Acid, m.p. 130° (B. **26**, R. 190).

Trimethyl Malic Acid, Hydroxy-Trimethyl-Succinic Acid, m.p. 155°, is obtained from dimethyl acetoacetic ester with hydrocyanic acid, with subsequent hydrolysis by hydrochloric acid (B. **29**, 1543, 1619). The corresponding *β-lactone acid*,  $\mathrm{\overline{OC(CH_3)(CO_2H).C(CH_3)_2CO}}$, m.p. 119°, is obtained from bromo-trimethyl-succinic acid and silver oxide, similarly to the production of *ββ*-dimethyl malic acid lactone.

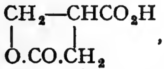
Isopropyl Malic Acid, m.p. 154°, from bromopimelic ester (A. **267**, 132).

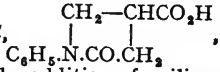
Paraconic Acids are *γ*-lactonic acids. Like the *γ*-hydroxyalkyl hydroxymalonic acids, they are converted by alkalis and alkali earths into salts of the corresponding hydroxysuccinic acids. When the latter are set free from their salts they immediately break down into water and lactonic acids. The alkyl paraconic acids are formed when sodium succinate or pyrotartrate and aldehydes (acetaldehyde, chloral, propionic aldehyde) are condensed by means of acetic anhydride at 100–120° (*Fittig*, A. **255**, 1):

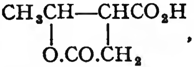


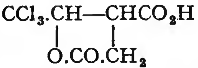
$$\mathrm{CH_3.CHO}+\begin{array}{l}\mathrm{CH_2.CO_2H}\\ |\\ \mathrm{CH_2.CO_2H}\end{array}=\begin{array}{l}\mathrm{CH_3.CH{-}CH.CO_2H}\\ \quad|\qquad|\\ \quad\mathrm{O.CO.CH_2}\end{array}+\mathrm{H_2O}$$

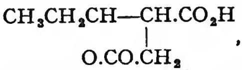
Succinic Acid. Methyl Paraconic Acid.

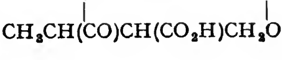
Paraconic Acid,  $\begin{array}{l}\mathrm{CH_2{-}CHCO_2H}\\ |\qquad|\\ \mathrm{O.CO.CH_2}\end{array}$, m.p. 57°, is best prepared by boiling itabromopyrotartaric acid with water and acidifying the calcium salt of the corresponding hydroxysuccinic acid—*itamalic acid*, formed on boiling itachloropyrotartaric acid with a soda solution. When boiled with bases, it forms salts of itamalic acid; it yields citraconic anhydride when it is distilled (A. **216**, 77; **255**, 10).

Pseudoitaconanilic Acid, γ-Anilidopyrotartrolactamic Acid,  $\begin{array}{l}\quad\;\mathrm{CH_2{-}CHCO_2H}\\ \quad\;|\qquad|\\ \mathrm{C_6H_5.N.CO.CH_2}\end{array}$, m.p. 190°, is formed from itaconic acid (A. **254**, 129), by the addition of aniline, and subsequent lactam formation.

γ-Methyl Paraconic Acid,  $\begin{array}{l}\mathrm{CH_3CH{-}CHCO_2H}\\ \quad|\qquad|\\ \quad\mathrm{O.CO.CH_2}\end{array}$, m.p. 84·5°. *Ethyl ester*, b.p.$_{17}$ 56°, is also prepared from acetosuccinic ester by reduction with amalgamated aluminium. Sodium ethoxide solution transforms and hydrolyses it into methyl itaconic acid. When distilled, methyl paraconic acid yields valerolactone ethylidene propionic acid (p. 298), methyl itaconic acid, and methyl citraconic acid (B. **23**, R. 91).

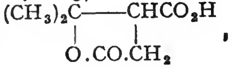
Trichloromethyl Paraconic Acid,  $\begin{array}{l}\mathrm{CCl_3.CH{-}CHCO_2H}\\ \quad\;|\qquad|\\ \quad\;\mathrm{O.CO.CH_2}\end{array}$, m.p. 97°, is changed by cold barium hydroxide solution into isocitric acid (*q.v.*). Reduction (C. 1897, II. 184; 1902, II. 343).

Ethyl Paraconic Acid,  $\begin{array}{l}\mathrm{CH_3CH_2CH{-}CH.CO_2H}\\ \qquad\quad\;|\\ \quad\;\mathrm{O.CO.CH_2}\end{array}$, m.p. 85° C., when distilled, breaks up chiefly into carbon dioxide and caprolactone (p. 374). Hydrosorbic Acid is formed at the same time (B. **23**, R. 93).

a-Methyl Paraconic Acid,  $\mathrm{CH_3CH(\overline{CO)CH(CO_2H)CH_2O}}$, m.p. 104°, is obtained by the action of sodium amalgam on β-formyl pyrotartaric ester, the reaction product of formic ester, pyrotartaric acid and sodium ethoxide. When heated it decomposes partly into water and pyrocinchonic anhydride (p. 518) (B. **37**, 1610).

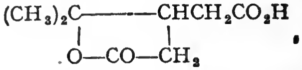
αγ-Dimethyl Paraconic Acid, $CH_3CH(CO)CH(COOH),CH(CH_3)O$, m.p. 131°, b.p.$_{14}$ 195°, is formed by reducing β-acetopyrotartaric ester with sodium amalgam. When heated it partially breaks down into water and methyl ethyl maleïc anhydride (p. 519), and into CO_2 and α-methyl β-pentenoic acid $(CH_3CH(CO_2H)\text{-}CH{:}CHCH_3$ (B. **37**, 1615).

Terebic Acid,



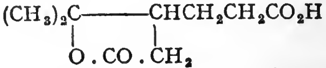
$$\begin{array}{l}(CH_3)_2C\text{———}CHCO_2H\\ \quad\;\; | \qquad\quad |\\ \quad\;\; O.CO.CH_2\end{array},$$

Terpenylic Acid,



$$\begin{array}{l}(CH_3)_2C\text{————}CHCH_2CO_2H\\ \qquad\; | \qquad\qquad\;\; |\\ \qquad\; O\text{—}CO\text{—}CH_2\end{array},$$

and **Homoterpenylic Acid**,



$$\begin{array}{l}(CH_3)_2C\text{————}CHCH_2CH_2CO_2H\\ \qquad\; | \qquad\qquad |\\ \qquad\; O.CO.CH_2\end{array}$$

are three oxidation products of turpentine oil. They will be discussed in connection with pinene (Vol. II.), the principal ingredient of the oil.

Propyl Paraconic Acid, $CH_3CH_2CH_2.CH(O)CH(CO_2H)CH_2CO$, m.p. 73·5°, yields, on distillation, γ-heptolactone (p. 375), heptylenic acid, $C_7H_{12}O_2$, and propylitaconic acid, $C_8H_{12}O_4$ (p. 518) (B. **20**, 3180).

Isopropyl Paraconic Acid, m.p. 69°, when distilled, decomposes into γ-isoheptolactone and isoheptylenic acid.

Isopropyl Isoparaconic Acid, $(CH_3)_2C(O)CH_2CH(CO).CH_2CO_2H$, m.p. 143°, is formed from isopropyl itaconic acid (p. 517) and hydrochloric acid at 130°, and by oxidation of isobutyl succinic acid by means of $KMnO_4$.

ααβ-Trimethyl Paraconic Acid, $OCH_2.C(CH_3)(CO_2H).C(CH_3)_2CO$, m.p. 270°, is formed from sodium trimethyl succinate and thioxymethylene, by the action of acetic anhydride. *Ethyl ester*, m.p. 34°; *chloride*, m.p. 140°; *amide*, m.p. 242°. The *anhydride*, m.p. 155°, is obtained, together with *Trimethyl Acetyl Itamalic Anhydride*, $OOC.C(CH_3)_2.C(CH_3)(OCOCH_3)CO$, b.p.$_{22}$ 185–195°, from trimethyl itamalic acid salts by boiling them with acetic anhydride (C. 1905, I. 1374).

HYDROXYGLUTARIC ACID GROUP

α-Hydroxyglutaric Acid, $CH_2<\begin{matrix}CH(OH).CO_2H\\CH_2CO_2H\end{matrix}$, m.p. 72°, occurs in molasses. It is formed from α-bromoglutaric acid (C. 1902, II. 187); and by the action of nitrous acid on α-aminoglutaric acid. It also occurs in the reaction products of nitric acid on casein (C. 1902, II. 285). It crystallizes with difficulty (A. **208**, 66; B. **15**, 1157). Its *lactone*, m.p. 50°, into which it readily passes when heated (A. **260**, 1129), is reduced to glutaric acid (p. 501) by hydriodic acid.

Glutaminic Acid, *α-Aminoglutaric Acid*, $CH_2<\begin{matrix}CH(NH_2)CO_2H\\CH_2CO_2H\end{matrix}$, m.p. 202° with decomposition, contains an asymmetric carbon atom (p. 29), and therefore can, like malic acid (p. 551), appear in three modifications. *Dextro-* or ordinary *glutaminic acid* occurs in the seeds of pumpkins and of vetches, as well as with aspartic acid in the molasses from beet-root, and is formed along with other compounds (p. 381) when proteins are boiled with dilute sulphuric acid. It consists of brilliant rhombohedra, soluble in hot water but insoluble in alcohol and ether. *Diethyl Ester*, b.p.$_{10}$ 140°, is prepared from the acid, alcohol, and hydrochloric acid (B. **34**, 453).

l-*Glutaminic Acid* is obtained from the inactive variety by means of *Penicillium glaucum* (p. 57).

Inactive [d+l]-*Glutaminic Acid*, m.p. 198°, results from ordinary glutaminic acid on heating it to 150–160° with barium hydroxide solution, and from α-isonitrosoglutaric acid (A. **260**, 119). By repeated crystallization it breaks down into d- and l-glutaminic acid (B. **27**, R. 269, 402; **29**, 1700). Resolution is also effected by means of the strychnine salts of r-benzoyl glutaminic acid (B. **32**, 2466). [d+l]-**Pyroglutaminic Acid**, m.p. 182–183°, is the γ-lactam of the glutaminic acid, which results on heating ordinary glutaminic acid to 190°, and on continued heating breaks down into CO_2 and pyrrole (B. **15**, 1342):

$$\overline{COCH_2CH_2CH(CO_2H)NH} \longrightarrow \overline{CH:CH.CH:CH.NH}+CO_2+H_2O$$

Pyroglutamine Acid. Pyrrole.

Glutamine *α-Aminoglutaramic Acid*, $C_3H_5(NH_2)<^{CONH_2}_{COOH}$, occurs together with asparagine in beet-root, in the seeds of pumpkins and other plants (B. **29**, 1882, C. 1897, I. 105). Its optical rotation is not constant (B. **39**, 2932).

γ-**Carbovalerolactonic Acid**, *α-Methyl Glutolactonic Acid*, *Valerolactone γ-Carboxylic Acid*, $\overline{O.C(CH_3)(CO_2H)CH_2CH_2CO}$, m.p. 68–70°, is deliquescent, and is produced (1) by oxidizing γ-isocaprolactone (p. 374) or isocaproic acid with nitric acid (A. **208**, 62; B. **32**, 3661); and (2) by the action of potassium cyanide and hydrochloric acid on lævulinic acid.

γ-Carbovalerolactamic Acid Nitrile; *α-Methyl Pyrrolidone α-Carboxylic Acid Nitrile*, $\overline{HNC(CH_3)(CN).CH_2.CH_2.CO}$, m.p. 141°, is formed from lævulinic ester, hydrocyanic acid, and alcoholic ammonia (comp. B. **38**, 1215).

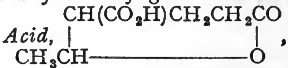
Isopropyl Glutolactonic Acid, $CO_2H.\overline{C(C_3H_7)CH_2.CH_2COO}$, m.p. 67°, is prepared from α-dimethyl lævulinic acid and hydrocyanic by means of hydrochloric acid (A. **288**, 185). *α-Hydroxy-γγ-dimethyl-glutolactonic Acid*, $\overline{O.CH(CO_2H).CH_2C(CH_3)_2CO}$, m.p. 85° (indefinite), results, together with dimethyl glutaconic acid, when alcoholic potassium hydroxide acts on α-bromo-dimethyl glutaric acid (C. 1902, I. 810; comp. also cyano-dimethyl-acetoacetic ester, p. 570). *α-Hydroxy-βγ-dimethyl-glutolactonic Acid*, *trans*-form, m.p. 142°, *cis*-form, liquid, b.p.$_{13}$ 194°, is formed from β-methyl lævulinic acid, hydrocyanic and hydrochloric acids (C. 1900, II. 242). *α-Hydroxy-αγγ-trimethyl-glutolactonic Acid*, $\overline{O.C(CH_3)(CO_2H)CH_2C(CH_3)_2CO}$, m.p. 103°, is prepared from bromo-trimethyl-glutaric acid and aqueous potassium hydroxide, and from mesitonic, hydrocyanic and hydrochloric acids (A. **293**, 220).

Mesitylic Acid, *α-Amino-αγγ-trimethyl-glutaric Acid Lactam*, $\overline{HNC(CH_3)(CO_2H)CH_2C(CH_3)_2CO}$, m.p. 174°, is prepared by boiling the addition product of mesityl oxide and hydrochloric acid with potassium cyanide and alcohol (see Mesitonic Acid, p. 423). If mesityl oxide alone be heated with two molecules of potassium cyanide in alcohol, there is formed on acidification *Trimethyl-α-hydroxy-glutaric Acid Dinitrile*, $NC.C(CH_3)_2CH_2C(CH_3)(OH)CN$, m.p. 166°, which on being warmed with hydrochloric acid yields mesitylic acid (C. 1904, II. 1108). Oxidation with permanganate in acid solution yields unsym.-dimethyl succinimide (B. **14**, 1074).

β-Hydroxyglutaric Acid, $CH(OH)<^{CH_2CO_2H}_{CH_2CO_2H}$, m.p. 95°, is obtained by the reduction of an aqueous solution of acetone dicarboxylic acid (B. **24**, 3250). It is decomposed on distillation into CO_2, H_2O and vinyl acetic acid (p. 297); Sulphuric acid and also boiling with aqueous alkali hydroxides (B. **33**, 1452) produce glutaconic acid (p. 520). Acetyl chloride gives rise to *Acetoxyglutaric Anhydride*, $CH_3COOCH(CH_2CO)_2O$, m.p. 88°. *Hydroxyglutaric Dimethyl Ester*, b.p.$_{11}$ 150°, yields *acetoxyglutaric ester*, which on distillation under ordinary pressures breaks down into glutaconic ester (B. **25**, 1976; C. 1903, II. 1315). *β-Hydroxyglutaric Diamide* is converted by sulphuric acid into glutaconimide. *β-Chloroglutaric Acid* is obtained from glutaconic acid and hydrochloric acid. From it and from glutaconic acid ammonia produces *β-Aminoglutaric Acid*, $CO_2H.CH_2CH(NH_2)CH_2CO_2H$, m.p. 248° with decomposition. *β-Bromoglutaric Acid*, m.p. 139° (C. 1899, II. 28).

sym.-*Alkyl β-Hydroxyglutaric Acids* are also formed by condensation of formic ester with α-bromo-fatty esters by means of zinc (see formation of secondary alcohols, p. 106); α-bromopropionic ester yields *αγ-Dimethyl β-Hydroxyglutaric Acid*; α-bromobutyric acid gives *αγ-Dimethyl β-Hydroxyglutaric Acid*; α-bromoisobutyric ester produces *ααγγ-Tetramethyl β-Hydroxyglutaric Acid* (C. 1898, II. 415, 885; 1900, II. 529; 1902, II. 107).

αα-Dimethyl β-Hydroxyglutaric Acid, m.p. 169°, and *ααγ-Trimethyl β-Hydroxyglutaric Acid*, *cis*-form, m.p. 115°; *trans*-form, m.p. 155°, are obtained from the corresponding di- and trimethyl acetone dicarboxylic esters (p. 569) (C. 1903, I. 76; 1904, I. 720). *ααβ-Trimethyl β-Hydroxyglutaric Ester* is prepared from α-dimethyl acetoacetic ester, bromacetic ester, and zinc (C. 1903, II. 1315). The acetylated esters of these acids yield alkyl glutaconic acids when distilled.



δ-Caprolactone γ-Carboxylic Acid, $\begin{array}{l} \quad\; CH(CO_2H)CH_2CH_2CO \\ \quad\;| \qquad\qquad\qquad\qquad\quad | \\ CH_3CH\text{———————}O \end{array}$, m.p. 197°, is formed when α-acetoglutaric acid (p. 570) is reduced (B. **29**, 2368). On dry distillation it yields γδ-hexenic acid (p. 299) and α-ethylidene glutaric acid (p. 522).

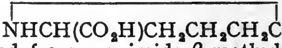
γ-Valerolactone β-Acetic Acid, $CO\begin{cases} O\text{—}CHCH_3 \\ CH_2.\dot{C}HCH_2CO_2H \end{cases}$, m.p. 84°; *αγ-Heptolactone β-Acetic Acid*, m.p. 88°, are obtained by reduction of the β-acyl glutaric acids (p. 570), or their *dilactones* (A. **314**, 13).

HIGHER HYDROXY-DICARBOXYLIC ACIDS

αα-Hydroxyadipic Acid (B. **28**, R. 466). *α-Hydroxysebacic Acid* (B. **27**, 1217).

α-Hydroxy-α-methyl-adipic Acid, $CO_2H.C(CH_3).(OH)[CH_2]_3CO_2H$, m.p. 92°, is prepared from γ-acetobutyric acid, potassium cyanide, and hydrochloric acid. On dry distillation it gives a mixture of γδ- and δε-hexenic acids, which are characterized by their ability to be converted into α- and δ-caprolactone (A. **313**, 371).

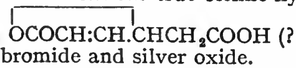
β-Methyl β-Hydroxyadipic Acid, $COOH.CH_2C(CH_3)(OH)CH_2CH_2COOH$, and *ααγ-Trimethyl β-Hydroxyadipic Acid*, $CO_2H.C(CH_3)_2C(CH_3)(OH)CH_2CH_2COOH$; their *lactone esters* are formed by condensation of bromacetic ester and α-bromisobutyric ester with lævulinic acid by means of zinc. The latter lactone ester is easily decomposed by alkalis into isobutyric acid and lævulinic acid (C. 1900, I. 1014; B. **36**, 953).



α-Amino-adipic Acid, $COOH.CH(NH_2)CH_2CH_2CH_2CO_2H$, m.p. 206° with decomposition, is formed from α-oximido-adipic acid (p. 570) by reduction with tin and hydrochloric acid; also, by hydrolysis and decomposition of cyanopropyl phthalimidomalonic ester, $C_6H_4(CO)_2NC(CO_2R)_2CH_2CH_2CH_2CN$, the product of reaction of sodium phthalimidomalonic ester and chlorobutyronitrile. It is sparingly soluble in water. When heated, it yields water and a *lactam*, *α-Piperidone α₁-Carboxylic Acid*, $\overline{NHCH(CO_2H)CH_2CH_2CH_2CO}$, m.p. 178°. *α-Amino-β-methyl-adipic Acid* is prepared from α-oximido-β-methyl-adipic acid. In the free state it immediately changes into its *lactam*, m.p. 144° (B. **38**, 1654; C. 1903, II. 33). *α-Aminopimelic Acid*, $NH_2CH(COOH)[CH_2]_4COOH$, m.p. 225° with decomposition, is obtained from α-oximidopimelic acid.

B. AND C. HYDROXY-OLEFINE CARBOXYLIC ACIDS AND HYDROXY-OLEFINE DICARBOXYLIC ACIDS

The following is derived from the true olefine-hydroxy-dicarboxylic acids:



Monolactonic Acid, $\overline{OCOCH{:}CH.C}HCH_2COOH$ (?), m.p. 122–125°, is obtained from hydromuconic dibromide and silver oxide.

The *aci*- or *enol*-forms of the *β-aldo*- and *β-keto-dicarboxylic acids* can also be included; see *formyl and acetyl malonic acids* (pp. 561, 564), *formyl* and *acetyl succinic acids* (pp. 561, 568), *α-acetyl glutaric acid* (p. 570), *oxalacetic acid* (p. 564), *acetone-dicarboxylic acid* (p. 568), *α-formyl* and *α-acetyl glutaconic acid* (pp. 561, 571), etc.

16. ALDODICARBOXYLIC ACIDS

A. β-Aldodicarboxylic Acids. The simplest member, (1) *Formyl Malonic Acid,* $OCH.CH(CO_2H)_2$, is unknown in the free state. From its corresponding *aci-* or *enol-*form (see p. 560) are derived the following:—

Hydroxymethylene Malonic Ester, $HOCH:C(CO_2C_2H_5)_2$, b.p. 218°, exists in the form of its *ethyl ether, Ethoxymethylene Malonic Ester,* $C_2H_5O.CH:C(CO_2C_2H_5)_2$, b.p. 280°, which is prepared from malonic ester and orthoformic ester by boiling with acetic anhydride and zinc chloride. The ethyl ether is "hydrolysed" by alcoholic potassium hydroxide into the potassium salt of hydroxymethylene malonic ester. It can also easily unite with more malonic ester to form a dicarboxyglutaconic ester $(RO_2C)_2CH—CH{\equiv}C(CO_2R)_2$. This substance is decomposed by many reactions into derivatives of hydroxymethylene malonic ester; ammonia produces *Aminomethylene Malonic Ester,* $H_2N.CH:C(CO_2C_2H_5)_2$, m.p. 67°, which can be formed directly from ammonia and ethoxymethylene malonic ester; hydrazine, hydroxylamine, and amidines give rise to *cyclic derivatives* of hydroxymethylene malonic or formyl malonic acids (B. **26,** 2731; **27,** 1658; **30,** 821, 1083; J. Ch. S. **59,** 746). *Copper salt,* m.p. 138°.

(2) *Formyl Succinic Acid,* $OCH.CH(CO_2H)CH_2CO_2H$ is unknown in the free state. Derivatives are: *Hydroxymethylene Succinic Ester,* aci-*Formyl Succinic Ester,* $HOCH:C(CO_2C_2H_5)CH_2CO_2C_2H_5$, b.p.$_{16}$ 125°, is obtained from succinic ester, formic ester, and sodium ethoxide. With ferric chloride it produces a violet coloration. Reduction produces itamalic ester (p. 557), alkalis decompose it into succinic and formic acids (B. **26,** R. 91; **27,** 3186. Action of Hydrazine, see B. **26,** 2061).

Aconic Acid: aci-*Formyl Succinic Acid Lactone,* $OCH:C(CO_2H)CH_2CO$, m.p. 164°, is formed when itadibromopyrotartaric acid is boiled with water; *methyl ester,* m.p. 85°. The acid yields formic and succinic acids when boiled with barium hydroxide; reduction produces paraconic acid (p. 557); phenylhydrazine gives the phenylhydrazone of β-formyl propionic hydrazide (p. 406) as well as CO_2; whilst with aconic methyl ester it forms the *phenylhydrazone,* of *formyl succinic monoester phenylhydrazide,* m.p. 167° (A. Spl. I. 347; **329,** 373; B. **31,** 2722).

Formyl Pyrotartaric Ester (B. **37,** 1610).

(3) *α-Formyl Glutaconic Acid,* $OCH.CH(CO_2H)CH:CHCO_2H$, is also a hypothetical acid, of which the following are derivatives:—

Coumalic Acid, *α-Pyrone-*3*-carboxylic Acid, α-*aci*-Formyl Glutaconic Acid Lactone,* $OCH:C(CO_2H)CH:CH.CO$, m.p. 206° with decomposition, is formed from malic acid by heating it with concentrated sulphuric acid or with zinc chloride, with probably an intermediate formation of hydroxymethylene acetic acid, $HOCH:CHCO_2H$ (p. 401), which, with the concentrated sulphuric acid, gives coumalic acid. This substance yields yellow salts with excess of alkali, like chelidonic and meconic acids (*q.v.*). Boiling with barium hydroxide solution decomposes it into formic and glutaconic acids; boiling with dilute sulphuric acid gives two molecules of CO_2 and crotonaldehyde. Ammonia produces the aci-*formyl glutaconic acid lactam, β-hydroxynicotinic acid,* $HN.CH:C(CO_2H)$:-$CH:CHCO$. Hydrazine causes decomposition of the production of the lactazam of hydroxymethylene acetic acid, *pyrazolone* (p. 406) (A. **264,** 269; B. **27,** 791). Methyl alcohol and hydrochloric acid cause fracture of the lactone ring and formation of

Methoxymethylene Glutaconic Ester, $CH_3COCH:C(CO_2CH_3)CH:CHCO_2CH_3$, m.p. 62° (A. **273,** 164).

B. γ-Aldodicarboxylic Acids.

Acetal Malonic Ester, $(C_2H_5O)_2CHCH_2(CO_2C_2H_5)_2$, b.p.$_{15}$ 152°, and *acetal methyl malonic ester* are prepared from sodium malonic ester and sodium methyl malonic ester with bromacetal. The free acids lose water and form β-formyl fatty acids (p. 402).

17. KETONE-DICARBOXYLIC ACIDS

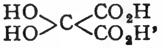
Dibasic carboxylic acids, containing a ketone group in addition to the carboxyl groups, are mostly synthesized as follows :—

1. By the introduction of acid radicals into malonic esters.
2. By introducing the residues of acid esters into acetoacetic ester.
3. By the condensation of oxalic esters with fatty acid esters.
4. By condensation of carboxylic anhydrides with tricarballylic acids.
5. From sec.-hydroxydicarboxylic acids or tert.-hydroxytricarboxylic acids by oxidation or decomposition.

These methods of formation will be more fully considered under the individual groups of the monoketone carboxylic acids. The position of the two carboxyl groups is again the basis for their classification, whereby the *ketomalonic acid group*, the *ketosuccinic acid group*, the *ketoglutaric acid group*, etc., are differentiated.

KETOMALONIC ACID GROUP

(1) **Mesoxalic Acid,** *Dihydroxymalonic Acid,* [Propanediol diacid],



$$\begin{matrix}HO\\HO\end{matrix}\!>C<\!\begin{matrix}CO_2H\\CO_2H\end{matrix},$$

m.p. 115°, like ordinary oxalic acid, glyoxylic acid, and other substances possessing adjacent CO groups, firmly holds a molecule of water, which is assumed to be present, not as water of crystallization, but to be combined with the CO-groups:

$(HO)_3C—C(OH)_3$	$(HO)_2CH—CO_2H$	$(HO)_2C=(CO_2H)_2$
Ortho-oxalic Acid.	Orthoglyoxylic Acid.	Orthomesoxalic Acid.

Furthermore, esters of mesoxalic acid exist, derived from both forms, and are known as *oxo-* and *dihydroxymalonic acid esters.* Mesoxalic acid is prepared (1) from alloxan (p. 578) or mesoxalyl urea, an oxidation product of urea when boiled with barium hydroxide solution ; (2) from dibromomalonic acid, by boiling barium hydroxide solution, silver oxide, or aqueous sodium hydroxide (method of formation : B. **35,** 1819) ; (3) from aminomalonic acid by oxidation with iodine in KI solution ; (4) from glycerol, by oxidation with nitric acid, sodium nitrate, and bismuth subnitrate (B. **27,** R. 666).

Mesoxalic acid crystallizes in deliquescent prisms. At higher temperatures it decomposes into CO_2 and glyoxylic acid, $CHO.CO_2H$ (p. 400). It breaks up into CO and oxalic acid on the evaporation of its aqueous solution.

Mesoxalic acid behaves like a ketonic acid, inasmuch as it unites with primary alkali sulphites ; and when acted on by sodium amalgam in aqueous solution, it is changed to tartronic acid (p. 549). It combines with hydroxylamine and phenylhydrazine.

Salts.—Calcium mesoxalate, $C(OH)_2(CO_2)_2Ca$, and *barium mesoxalate,* are crystalline powders, not very soluble in water ; *ammonium salt,* $C(OH)_2.(CO_2.NH_4)_2$, crystallizes in needles ; *silver salt,* $C(OH)_2.(CO_2Ag)_2$, when boiled with water yields mesoxalic acid, silver oxalate, silver, and CO_2; *bismuth salt*, B. **27**, R. 667.

Esters.—Two series of esters may be derived from mesoxalic acid —the anhydrous or *ketomalonic esters*, $CO(CO_2R')_2$, and the *dihydroxymalonic esters*, $C(OH)_2(CO_2R')_2$. The keto- or oxo-malonic esters absorb water with avidity, and thereby change into their corresponding dihydroxymalonic esters. The two compounds bear the same relation to each other that chloral bears to chloral hydrate:

$$CCl_3.CHO \quad \text{Chloral} \xrightarrow{H_2O} CCl_3.CH(OH)_2 \quad \text{Chloral Hydrate}$$

$$CO(CO_2C_2H_5)_2 \ \text{Ketomalonic Ester} \xrightarrow{H_2O} C(OH)_2(CO_2C_2H_5)_2 \ \text{Dihydroxymalonic Ester.}$$

During preparation a mixture of both forms is obtained if water is not excluded. Nevertheless, the hydrates easily pass into the anhydrous compounds when heated under reduced pressure.

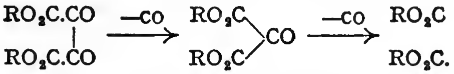
Mesoxalic ester is produced (1) from mesoxalic acid, by the usual methods; (2) from isonitrosomalonic ester (below); or from malonic ester direct by the action of nitrous gases (C. 1903, II. 658; 1905, II. 120; 1906, II. 320):

$$2(RO_2C)_2CH_2 \xrightarrow{N_2O_3} 2(RO_2C)_2C:NOH \xrightarrow{N_2O_3} 2(RO_2C)_2C:O+2N_2O+H_2O$$

(3) From bromotartronic ester acetate or bromonitromalonic ester by the action of heat (B. **25**, 3614: **37**, 1775):

$$(RO_2C)_2C(OCOCH_3)Br \xrightarrow{-CH_3COBr} RO_2C.CO \xleftarrow{-NOBr} BrNO_2C(CO_2R)_2$$

(4) from dihydroxysuccinic ester when heated, some oxalic ester being also formed (B. **27**, 1305):



Ketomalonic Ethyl Ester, $CO(CO_2C_2H_5)_2$, b.p.$_{14}$ 101°, $D_{16}=1{\cdot}1358$, possesses a bright greenish-yellow colour. It is a mobile liquid, with a faint but not disagreeable odour. *Dihydroxymalonic Methyl Ester*, $(HO)_2C(CO_2CH_3)_2$, m.p. 81°. *Dihydroxymalonic Ethyl Ester*, $C(OH)_2(CO_2C_2H_5)$, m.p. 57°, dissolves easily in water, alcohol, and ether. *Diethoxymalonic Ester*, $(C_2H_5O)_2C(CO_2C_2H_5)$, m.p. 43°, b.p. 225° (C. 1897, II. 569). *Diacetoxymalonic Ester*, $(CH_3CO.O)_2C(CO_2C_2H_5)_2$, m.p. 145°. *Dihaloid-malonic Acids*, $H_2C(CO_2H)_2$ (p. 489).

Nitrogen Derivatives of Mesoxalic Acid.

Nitrobromomalonic Acid, $BrNO_2C(CO_2R)_2$; *methyl ester*, b.p.$_{18}$ 133°, and *ethyl ester*, b.p.$_{11}$ 137°, are formed from nitromalonic ester (p. 549) and bromine. As in other per-substituted nitromethanes (p. 155) the halogen is easily replaceable. Decomposition into ketomalonic ester (see above) (B. **37**, 1775).

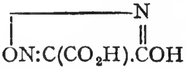
Diaminomalonamide, $(NH_2)_2C(CONH_2)_2$, is prepared from dibromomalonic ester and ammonia. It consists of white crystals, and when heated, easily changes into *imidomalonamide*, $NH:C(CONH_2)_2$. *Tetramethyl Diaminomalonic Ester*, $[(CH_3)_2N]_2C(COOCH_3)_2$, m.p. 84°, is also obtained from dibromomalonic ester and $NH(CH_3)_2$. *Dianilinomalonic Ester*, $(C_6H_5NH)_2C(COOCH_3)_2$, m.p. 125°, results from the action of aniline on dibromomalonic ester (B. **35**, 1374; 1813).

Oximidomesoxalic Acid, Isonitrosomalonic Acid, $HON{=}C(CO_2H)_2$, m.p. 126°, with decomposition into HNC, CO_2, and H_2O. It is formed when hydroxylamine acts on mesoxalic acid; also from *violuric acid* (described in connection with alloxan—isonitroso-malonyl-urea (B. **16**, 608, 1021); also from *isonitrosomalonic ester*, $HON:C(CO_2R)_2$; *methyl ester*, m.p. 67°, b.p.$_{18}$ 168°, *ethyl ester*, b.p.$_{12}$ 172°, which are prepared from the malonic ester, sodium alcoholate, and alkyl nitrites. They form yellow alkali salts. *Amides* and *alkyl amides* of isonitrosomalonic acid (C. 1903, I. 441, 448).

Oximidomesoxalic Nitrile Ester, Isonitrosocyanacetic Ester, $HON:C(CN).CO_2C_2H_5$, m.p. 128°, is formed from sodium cyanacetic ester and amyl nitrite.

It is a stronger acid than acetic acid (B. **24**, R. 595; C. 1902, **II.** 1412). The free *isonitrosocyanacetic acid,* m.p. 129° with decomposition, has been obtained in different ways: (1) from dihydroxytartaric acid (*q.v.*) and hydroxylamine, some dioximidosuccinic acid being formed at the same time; (2) from furazan dicarboxylic acid, the anhydride of dioximidosuccinic acid (3) from furazan monocarboxylic acid (p. 545) (B. **24**, 1988; **28**, 72):

(4) by the action of N_2O_3 on isoxazolone hydroxamic acid, prepared from oxalacetic ester and 2 molecules of NH_2OH (see p. 567) (B. **28**, 761). Further derivatives of isonitrosomalonic acid are: *isonitrosocyanacetamide, desoxyfulminuric acid,* $HON:C(CN)CONH_2$ (p. 251): *Isonitrosocyanacetohydroxamic acid,* $HON{:}C(CN)C{\lessgtr}^{OH}_{NOH}$, is prepared from formyl chloridoxime and NH_3 (pp. 243, 249). *Oxyfurazan Carboxylic Acid,*



$$\begin{matrix} \overline{\quad\quad\quad\quad\quad} N \\ \| \\ ON:C(CO_2H).COH \end{matrix}$$

, is formed from hydroxyfurazanacetic acid (see Oxalacetic Ester, p. 566).

Phenylhydrazonomesoxalic Ester, $C_6H_5NHN:C(CO_2R)_2$, *dimethyl ester,* m.p. 62°; *diethyl ester,* an oil, is prepared (1) from mesoxalic ester and phenylhydrazine: (2) from sodium malonic ester and benzene diazonium salts (B. **24**, 866, 1241; **25**, 3183; **28**, 858; **37**, 4169).

Hydrolysis causes the formation first of the *monomethyl ester,* m.p. 125°, and *monoethyl ester,* m.p. 115°, and then of *Phenylhydrazonomesoxalic Acid,* $C_6H_5NHN:C(CO_2H)$, m.p. 163° with decomposition, which can also be obtained from mesoxalic acid and phenylhydrazine. *Phenylhydrazonomesoxalic Ester Nitrile, Benzene Azocyanacetic Ester,* $C_6H_5NHN:C(CN)CO_2C_2H_5$, or $C_6H_5N:NCH(CN)CO_2C_2H_5$, m.p. 125°, is formed from sodium cyanacetic ester and benzene diazonium chloride (B. **27**, R. 393; **28**, R. 997; C. 1906, II. 625); and also from potassium malonitrile and benzene diazonium salts. *Phenylhydrazonomesoxalic Dinitrile,* $C_6H_5NHN:C(CN)_2$ (B. **29**, 1174). *Phenylhydrazonomesoxalic Diamide,* m.p. 232° (B. **37**, 4173).

Hydrazonomesoxalic Diamide, $NH_2N:C(CONH_2)_2$, m.p. 175°, is formed from dibromomalonic diamide and hydrazine (B. **28**, R. 1052).

Oxazomalonic Acid is formed by the action of nitric oxide and sodium ethoxide on malonic ester. The product of reaction is unstable and forms a *sodium salt,* $N_2O:C(CO_2Na)_2+2H_2O$, with aqueous sodium hydroxide. This and other salts readily explode, especially when dry (B. **28**, 1795).

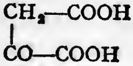
(2) **Acetyl Malonic Acid,** $CH_3CO.CH(CO_2H)_2$; *ethyl ester,* b.p.$_{17}$ 150°, results when sodium or, better, copper acetoacetic ester is acted on by chlorocarbonic ester (p. 419) (B. **21**, 3567; **22**, 2617). On hydrolysis it decomposes into CO_2, acetone, and acetic acid. *Acetomalonic Monoester Anilide,* $CH_3CO.CH(CONHC_6H_5)$-$CO_2C_2H_5$, m.p. 58, is formed by the union of acetoacetic ester and phenyl cyanate. It is decomposed by alkalis in the cold into acetic acid and malonic acid anilide (B. **33**, 2002).

Acetyl Cyanacetic Ester, Cyanacetoacetic Ester, $CH_3CO.CH(CN).CO_2C_2H_5$, m.p. 56°, b.p.$_{15-20}$ 119°, is prepared (1) from the sodium or pyridine salt of cyanacetic ester and acetyl chloride; if acetic anhydride be employed, cyanacetyl acetone is also formed; (2) from dicyanacetoacetic ester (p. 417) by separating hydrocyanic acid by alkalis. When the salts of cyanacetoacetic ester are alkylated and acylated *O-derivatives of the enolfrom* result: $CH_3C(OCH_3):C(CN)CO_2CH_3$, m.p. 97°; $CH_3C(OCOCH_3):C(CN)CO_2CH_3$ and ammonia yield $CH_3C(NH_2)$:-$C(CN)CO_2CH_3$, m.p. 181° (C. 1904, I. 1135; B. **37**, 3384). *Propionyl Cyanacetic Ester,* b.p.$_{50}$ 155–165° (B. **21**, R. 187, 354; **22**, R. 407; C. 1899, I. 185).

KETOSUCCINIC ACID GROUP

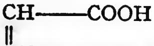
1. Oxalacetic Acid, *Ketosuccinic Acid* [Butanone di-acid], $C_4H_4O_5$, is relatively stable in the free state, and is simultaneously an α- and

β-keto-acid. In this connection, the desmotropic enol formulæ of hydroxymaleïc and hydroxyfumaric acids should be compared:



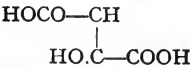
$$\begin{array}{l}CH_2—COOH\\ |\\ CO—COOH\end{array}$$

Ketosuccinic Acid.



$$\begin{array}{l}CH——COOH\\ \|\\ C(OH)—COOH\end{array}$$

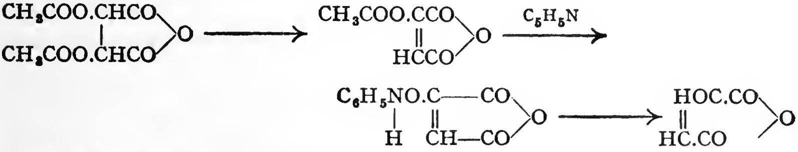
Hydroxymaleïc Acid.



$$\begin{array}{r}HOCO—CH\\ |\\ HO.C—COOH\end{array}$$

Hydroxyfumaric Acid.

Oxalacetic acid is prepared (1) from synthetic oxalacetic esters (p. 566) by hydrolysis with concentrated hydrochloric acid in the cold (C. 1904, I. 85); (2) from malic acid (hydroxysuccinic acid) and permanganate or H_2O_2 and ferrous salts at a low temperature (C. 1900, I. 328; 1901, I. 168); (3) from teraconic acid (isopropylidene succinic acid (p. 518) by cleavage of the chain with permanganate; (4) from diacetyl tartaric anhydride (*q.v.*) or acetoxymaleïc anhydride (see below), pyridine and acetic acid, there is formed the pyridine salt of hydroxymaleïc anhydride which with dilute acids yields oxalacetic acid or hydroxymaleïc acid respectively (B. **40**, 2282):



When the pyridine salt of hydroxymaleïc anhydride is treated with 12% sulphuric acid, the *Hydroxymaleïc Acid*, m.p. 152°, is formed, which is converted by 30% acid into *Hydroxyfumaric Acid*, m.p. 184°, from the salts of which dilute acids regenerate hydroxymaleïc acid; probably ketosuccinic acid is formed as an intermediate product. Hydroxyfumaric and hydroxymaleïc acids show equally strong colorations with ferric chloride and decolorations with permanganate (*reactions of the enol group*). The heat of combustion of hydroxymaleïc (286·58 cals.) is 10·8 cals. more than that of hydroxyfumaric acid (*see* Fumaric or Maleïc Acids, pp. 60, 512).

Hydroxymaleïc Anhydride, aci-*Oxalacetic Anhydride*, $HO.C_2H(CO)_2O$, m.p. 85° with transformation, is prepared from the pyridine salt, m.p. 108° (see above), by the action of HCl in ether. It is very hygroscopic. Acetyl chloride produces from it *Acetoxymaleïc Anhydride*, $CH_3COO.C_2H(CO_2)O$, m.p. 90°, which is also formed when oxalacetic acid and acetylene dicarboxylic acid are acted on by acetic anhydride at 100° (B. **28**, 2511).

The hydroxymaleïc anhydride, when treated with aniline at −20° and acidified with 5N hydrochloric acid, is changed into *Hydroxymaleïnanilic Acid*, $C_6H_5NHCOC(OH):CHCOOH$, m.p. 113° with decomposition, which is converted by 10N sulphuric acid into *Hydroxyfumaranilic Acid*, m.p. 140° with decomposition. The ethyl ester of *Oxalacetanilic Acid*, $C_6H_5NHCOCH_2CO.CO_2C_2H_5$, the third *position isomer*, is obtained from oxalic ester, acetanilide, and sodium ethoxide. The anil acids are converted by acetyl chloride into *hydroxymaleïnanil* (and further into *Acetoxymaleïnanil*, $CH_3COO.C_2H(CO)_2NC_6H_5$, m.p. 126°), which easily loses water and forms the dimolecular *Xanthoxalanil*; aniline produces *Anilinomaleïnanil*, $C_6H_5NH.C_2H(CO)NC_6H_5$, m.p. 233° (see above) (B. **40**, 2282).

Hydroxyfumaranilic acid and hydroxymaleïnanilic acid, which are fairly stable alone, are decomposed even at 0° by aniline into CO_2 and pyroracemic anilide (p. 409).

Oxalacetic Ethyl Ester, $C_2H_5OOC.COCH_2COOC_2H_5$ or $C_2H_5OOC.$-$C(OH):CH.COOC_2H_5$, b.p.$_{24}$ 132°, and the *methyl ester,* m.p. 770°, labile form, m.p. 87°, b.p.$_{39}$ 137° (A. **277**, 375; B. **39**, 256), are formed from oxalic and acetic esters (p. 412) by means of sodium alcoholate (*W. Wislicenus*); also from acetylene dicarboxylic esters (p. 523) by the addition of water by warming with sulphuric acid; and from the silver salt of oxalacetic acid and iodo-alkyls. When boiled with alkalis, the ethyl ester undergoes "acid cleavage" into oxalic acid, acetic acid, and alcohol; when boiled with dilute sulphuric acid "ketone cleavage" occurs into CO_2 and pyroracemic acid, $CH_3.CO.CO_2H$ (p. 407). When heated under ordinary pressure it suffers "carbon monoxide cleavage" into CO and malonic ester, with pyroracemic ester as a by-product (B. **28**, 811):

$CO_2C_2H_5.CO.\boxed{CH_2CO_2C_2H_5}$ Acid cleavage

$CO_2C_2H_5.CO.CH_2\boxed{CO_2C_2H_5}$ Ketone cleavage

$CO_2C_2H_5.\boxed{CO}.CH_2CO_2C_2H_5$ Carbon monoxide cleavage

Reduction converts oxalacetic ester into the ester of i-malic acid (B. **24**, 3416).

Ferric chloride colours a solution of the ester a deep red. Copper acetate precipitates the ethyl ester as a green *copper salt* $(C_8H_{11}O_5)_2$-$Cu+H_2O$, m.p. 155°, anhydrous, m.p. 163°. If this salt is boiled with methyl alcohol, it is converted into the copper salt of *Oxalacetic Methyl Ethyl Ester,* $COOCH_3.COCH_2COOC_2H_5$, b.p.$_3$ 110° (A. **321**, 372).

Ammonia becomes added on to oxalacetic ester, forming what is probably the *ammonium salt* of the *aci-oxalacetic ester* (hydroxyfumaric or hydroxymaleïc ester), $C_2H_5OOC.C(ONH_4):CH.COOC_2H_5$, m.p. 83°. It becomes gradually changed into oxalocitric lactone ester, which is also formed from oxalacetic ester and a tertiary amine (comp. B. **39**, 207).

Aminofumaric Ester, $C_2H_5OCO.C(NH_2):CH.CO_2C_2H_5$, b.p.$_{20}$ 142°, is formed when the above ammonium salt is rapidly distilled; also, from chlorofumaric and chloromaleïc ester and ammonia. Copper acetate slowly regenerates the copper oxalacetate ester (A. **295**, 344). *Aminofumaramide Ester,* m.p. 139°, and *Aminomaleïc Amide Ester,* m.p. 119° (C. 1897, I. 364).

Similarly to acetic ester, oxalic ester also condenses with acetonitrile (B. **25**, R. 175), and with acetanilide (see above) (B. **24**, 1245).

unsym.-*Diethoxysuccinic Ester,* $CO_2C_2H_5.C(OC_2H_5)_2CH_2CO_2C_2H_5$, is formed together with ethoxyfumaric ester (below) both from ordinary dibromosuccinic ester and acetone dicarboxylic ester by the action of sodium ethoxide. The resulting *diethoxysuccinic acid,* when allowed to stand under greatly reduced pressure or when heated to 100°, loses ether and becomes converted into oxalacetic acid (B. **29**, 1792).

Ethoxyfumaric Ester, $C_2H_5OOC.C(OC_2H_5):CH.COOC_2H_5$, b.p.$_{11}$ 130°, is prepared from silver oxalacetic ester and iodoethane, and from dibromosuccinic ester, with simultaneous formation of diethoxysuccinic ester (see above), by taking up alcohol. The free *Ethoxyfumaric Acid,* m.p. 133°, is obtained from the ester by the action of cold dilute alkali. Acetic anhydride converts it into the fluid *ethoxymaleïc anhydride,* which takes up water and forms *Ethoxymaleïc Acid,* m.p.

126°. Both acids are hydrolyzed by hydrochloric acid into oxalacetic acid (B. **28**, 2512; **29**, 1792).

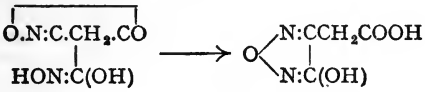
Methyl Oxalacetic Ester, Oxalopropionic Ester, $CO_2C_2H_5.CO.CH(CH_3).CO_2C_2H_5$, is formed from oxalic ester and propionic ester. *Methyl Oxalacetanil*, $CO.CO.CH(CH_3)CONC_6H_5$, m.p. 192°, is prepared from oxalic ester and propionanilide; also from *anilinocitraconanil* $CO.C(NHC_6H_5):C(CH_3)CONC_6H_5$, the product of action of chloro- or bromo-citraconanil (p. 516), aniline and sulphuric acid (B. **24**, 1256; **35**, 1626).

Ethyloxalacetic Ester, Oxalobutyric Ester, $CO_2C_2H_5.CO.CH(C_2H_5)CO_2C_2H_5$ (B. **20**, 3394). *Dimethyl Oxalacetic Ester, Oxalisobutyric Ester*, $CO_2C_2H_5.CO.C(CH_3)_2CO_2C_2H_5$, b.p.$_{11}$ 117°, is obtained from oxalic ester, bromisobutyric ester, and magnesium (B. **41**, 964). *Methyl Ethyl Oxalacetic Ester*, b.p.$_{14}$ 134° (C. 1905, I. 1590).

Nitrogen Derivatives of Oxalacetic Acid (B. **24**, 1198). For the salt-like addition products of oxalacetic anhydride and oxalacetic ester with pyridine and ammonia, and their reaction products, see pp. 564, 565.

Oximes and Phenylhydrazones. α-Oximidosuccinic Acid, m.p. 143° with decomposition, is formed from oxalacetic acid and hydroxylamine. Acetic anhydride converts it into the *β-acid*, m.p. 126° with decomposition (C. 1901, I. 353). *β-Oximidosuccinic Monoethyl Ester*, m.p. 54°, is prepared from the oxime of oxalacetic ester and water; and *α-Oximidosuccinic Ethyl Ester*, m.p. 107°, is obtained from di-isonitroso-succinyl-succinic ester and water. When heated they both yield CO_2 and α-oximidopropionic ester, $CH_3C:N(OH)CO_2C_2H_5$. Both monoesters are given the formula $CO_2H.CH_2C:N(OH)CO_2C_2H_5$, and are assumed to be stereoisomers (B. **24**, 1204). *Oximidosuccinic ester*, $CO_2C_2H_5.C:N(OH).CH_2CO_2C_2H_5$, is a colourless oil (B. **21**, R. 351). Comp. *Aspartic Acid* and *Asparagine* (pp. 553, 554).

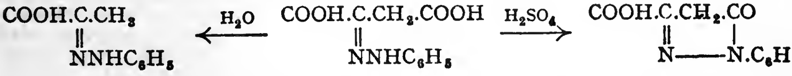
Hydroxylamine and ammonia act on oxalacetic ester producing the ammonium salt of *isoxazolone hydroxamic acid*, which is converted by alkalis into *hydroxyfurazan acetic acid*,



$$\begin{array}{l} O.N:C.CH_2.CO \\ \quad\quad\; | \\ HON:C(OH) \end{array} \longrightarrow O\begin{array}{l} \diagup N:CCH_2COOH \\ \quad\;\; | \\ \diagdown N:C(OH) \end{array}$$

which is oxidized by permanganate into hydroxyfurazan carboxylic acid (B. **28**, 761).

Phenylhydrazine reacts with oxalacetic acid to form a *phenylhydrazone*, $COOH.C(NNH.C_6H_5)CH_2.COOH$, m.p. 95°, with decomposition into CO_2 and pyroracemic acid phenylhydrazone. It undergoes the same decomposition when boiled with water, but when heated with acids, it forms *phenylpyrazolone carboxylic acid* or *lactazam* (p. 406) (C. 1902, II. 189):

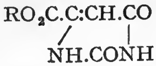


$$\begin{array}{l} COOH.C.CH_3 \\ \quad\quad\; \| \\ \quad NNHC_6H_5 \end{array} \xleftarrow{H_2O} \begin{array}{l} COOH.C.CH_2.COOH \\ \quad\quad\; \| \\ \quad NNHC_6H_5 \end{array} \xrightarrow{H_2SO_4} \begin{array}{l} COOH.C.CH_2.CO \\ \quad\quad\; \| \quad\quad | \\ \quad\quad N\text{——}N.C_6H_5 \end{array}$$

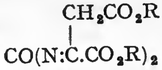
Phenylhydrazine becomes added to oxalacetic ester like ammonia (p. 566); the *addition product*, m.p. 105°, is either a phenylhydrazine salt of hydroxyfumaric ester or is analogous to an aldehyde-ammonia compound. It readily changes into *Oxalacetic Ester Phenylhydrazone*, m.p. 97°, which is also formed from acetylene dicarboxylic ester and phenylhydrazine. The reaction products of hydrazine and phenylhydrazine on oxalacetic acid also readily form lactazams or pyrazolone derivatives by loss of alcohol (see above) (A. **246**, 320; B. **25**, 3442; **26**, 1721).

Diazosuccinic Ester is formed when aspartic ester hydrochloride reacts with sodium nitrite. It is yellow in colour, and is easily decomposed. When boiled with water it forms fumaric ester; reduction re-produces aspartic ester. *Diazosuccinamide Methyl Ester*, $CH_3O_2C.CN_2.CH_2CONH_2$, m.p. 81°, is formed, together with fumaramide, from diazosuccinic methyl ester and ammonia (B. **19**, 2460; **29**, 763; **37**, 1264).

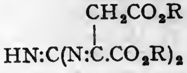
Urea unites with oxalacetic ester to form *Uracil Carboxylic Ester* (1), m.p. 189°, and *Dioxalacetic Ester Carbamide* (2), m.p. 104° ; guanidine produces *Dioxalacetic Ester Guanidine* (3), m.p. 147° with decomposition (C. 1898, I. 445):

(1) 

$$\begin{array}{l}RO_2C.C{:}CH.CO \\ \quad / \qquad\quad | \\ NH.CONH\end{array}$$

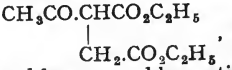
(2) 

$$\begin{array}{l}\qquad CH_2CO_2R \\ \qquad\quad | \\ CO(N{:}C.CO_2R)_2\end{array}$$

(3) 

$$\begin{array}{l}\qquad\quad CH_2CO_2R \\ \qquad\qquad | \\ HN{:}C(N{:}C.CO_2R)_2\end{array}$$

2. **Acetosuccinic Esters** and **Alkyl Acetosuccinic Esters** are produced when sodium acetoacetic esters and their monoalkyl derivatives are acted on by esters of the α-monohalogen fatty acids.

Acetosuccinic Ester, 

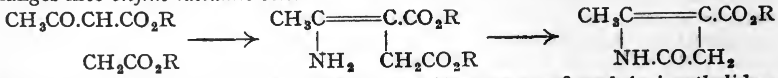
$$\begin{array}{l}CH_3CO.CHCO_2C_2H_5 \\ \qquad\quad | \\ \qquad CH_2.CO_2C_2H_5\end{array}$$

, b.p.$_{14}$ 141°, is prepared from sodium acetoacetic ester and brom- or chloracetic ester. The hydrogen atom of the CH- group, in the esters, can be replaced by alkyls, *e.g.*, by methyl:

α-*Methyl Acetosuccinic Ester*, $CH_3COC(CH_3)(CO_2C_2H_5).CH_2CO_2C_2H_5$, b.p. 263°, is formed from methyl acetoacetic ester and chloracetic ester.

β-*Methyl Acetosuccinic Ester*, $CH_3CO.CH(CO_2C_2H_5).CH(CH_3)CO_2C_2H_5$, b.p. 263°, from acetoacetic ester and α-bromopropionic ester.

When heated alone the acetosuccinic acids act as in the aci- or enol- form, lose alcohol and form *olefine lactone carboxylic acids* (C. 1898, I. 24). Ammonia and the primary amines produce *aminoethylidene succinic ester*, which readily changes into *olefine-lactamic ester*:

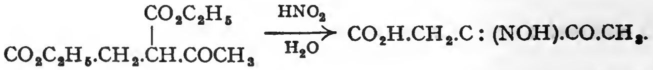


$$\begin{array}{l}CH_3CO.CH.CO_2R \\ \\ \quad CH_2CO_2R\end{array} \longrightarrow \begin{array}{l}CH_3C\!=\!\!=\!\!=\!C.CO_2R \\ \qquad |\qquad\quad | \\ \quad NH_2 \quad CH_2CO_2R\end{array} \longrightarrow \begin{array}{l}CH_3C\!=\!\!=\!\!=\!C.CO_2R \\ \qquad |\qquad\quad | \\ \quad NH.CO.CH_2\end{array}$$

Ammonia produces α-*Aminoethylidine Succinic Ester*, m.p. 72°, and *Aminoethylidene Succinimide*, which is converted by hydrochloric acid into *Acetosuccinimide*, m.p. 84–87° (A. **260**, 137; B. **20**, 3058; C. 1897, I. 283):

$$\begin{array}{l}CH_3C\!=\!\!=\!\!=\!C{-}CO \\ \quad |\qquad\quad |\qquad\quad \rangle NH \\ \;NH_2 \;\; CH_2.CO\end{array} \longrightarrow \begin{array}{l}CH_3CO.CH{-}CO \\ \qquad\quad |\qquad\quad \rangle NH. \\ \qquad CH_2{-}CO\end{array}$$

Acid cleavage changes acetosuccinic acids into acetic and *succinic* or *alkyl succinic acids* (pp. 492, 493). Ketone cleavage causes the formation of CO_2 and γ-*keto-acids* (p. 421). Nitrous acid causes acetosuccinic ester to lose alcohol and CO_2, and to change into *isonitrosolævulinic acid* (p. 547) (comp. Isonitrosoacetone, p. 354).



$$\begin{array}{l}\qquad\qquad CO_2C_2H_5 \\ \qquad\qquad\quad | \\ CO_2C_2H_5.CH_2.CH.COCH_3\end{array} \xrightarrow[H_2O]{HNO_2} CO_2H.CH_2.C:(NOH).CO.CH_3.$$

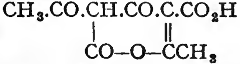
KETOGLUTARIC ACID GROUP

1. α-**Ketoglutaric Acid**, $COOH.CH_2CH_2.CO.COOH$, m.p. 113°, is obtained from oxalosuccinic ester by ketone cleavage (C. 1908, II. 786). *Cyanoximidobutyric Acid*, $CO_2H.CH_2.CH_2.C{=}(NOH)CN$, m.p. 87°, is a derivative of α-ketoglutaric acid. It is formed when cold sodium hydroxide acts on *furazan propionic acid* (p. 546). When it is boiled with sodium hydroxide α-*Oximidoglutaric Acid*, $CO_2H.CH_2.CH_2C{=}N(OH)CO_2H$, m.p. 152°, is produced (A. **260**, 106).

2. **Acetone-Dicarboxylic Acid,** β-*Ketoglutaric Acid*, $CO(CH_2CO_2H)_2$, m.p. about 130°, and decomposes into CO_2 and acetone. It may be obtained by warming citric acid with concentrated sulphuric acid (*v. Pechmann*, B. **17**, 2542; **18**, R. 468; A. **278**, 63), and by oxidizing it with permanganate (C. 1900, I. 328). The diethyl ester may be prepared by the action of alcoholic hydrochloric acid on γ-cyanacetoacetic ester.

Acetone dicarboxylic acid dissolves readily in water and ether. The alteration which takes place on heating the acid alone (see above), also occurs on boiling it with water, acids, or alkalis. The solutions of the acid are coloured violet by ferric chloride. Hydrogen reduces the acid to β-hydroxyglutaric acid (p. 558).

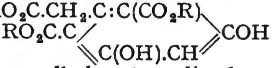
PCl_5 converts the acid into β-chloroglutaconic acid, $CO_2H.CH : CCl.CH_2CO_2H$. Hydroxylamine changes it to *Oximidoacetone Dicarboxylic Acid*, $CO_2H.CH_2.C(NOH)CH_2CO_2H + H_2O$, m.p. 54°, anhydrous, m.p. 89° (B. **23**, 3762). Nitrous acid converts acetone dicarboxylic acid into diisonitroso-acetone (p. 537) and CO_2 (B. **19**, 2466; **21**, 2998). The acid is condensed by acetic anhydride to *dehydracetocarboxylic acid*,



$$\begin{array}{l} CH_3.CO.CH.CO.C.CO_2H \\ \qquad\quad | \qquad\quad \| \\ \qquad CO{-}O{-}CCH_3 \end{array}$$

(A. **273**, 186).

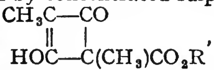
Acetone Dicarboxylic Ester, $RO_2C.CH_2COCH_2.CO_2R$; *methyl ester*, b.p.$_{12}$ 128°; *ethyl ester*, b.p.$_{12}$ 138° (B. **23**, 3762; **24**, 4095; C. 1906, II. 1395). Acid and alkaline reagents cause the esters to lose alcohol and water, and readily to condense to *orcinol ω,2,6-tricarboxylic ester*,



$$RO_2C.C \begin{array}{l} \diagup RO_2C.CH_2.C:C(CO_2R) \diagdown \\ \diagdown C(OH).CH \diagup \end{array} COH$$

(Vol. II.).

Sodium and iodo-alkyls produce alkyl acetone dicarboxylic esters, whereby the hydrogen atoms of the two CH_2-groups can be successively replaced by alkyl groups (B. **18**, 2289); it is, however, difficult to separate completely the various products of the reaction. *$\alpha\alpha_1$-Dimethyl Acetone Dicarboxylic Ester*, $CH_3CH(CO_2R)$-$COCH(CO_2R)CH_3$, is condensed by concentrated sulphuric acid into aci-*dimethyl-cyclobutanone carboxylic ester*,



$$\begin{array}{l} CH_3C{-}{-}CO \\ \quad \| \quad\;\; | \\ HOC{-}{-}C(CH_3)CO_2R \end{array}$$

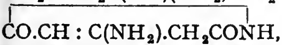
, a monobasic acid (B. **40**, 1604), of which the sodium salt reacts with iodomethane in alcohol to form *trimethyl acetone dicarboxylic ester*. This is also formed from $\alpha\alpha$-diethyl acetone dicarboxylic ester, $(CH_3)_2C(CO_2R).COCH_2CO_2R$, the product of reaction of dimethyl malonic ester, acetic ester, and sodium (C. 1903, I. 76; II. 190). *$\alpha\alpha$-Diethyl Acetone Dicarboxylic Ester*, $CO_2C_2H_5.C(C_2H_5)_2COCH_2CO_2C_2H_5$, is formed by the carbon monoxide cleavage of α-diethyl γ-oxalyl acetoacetic ester, $C_2H_5O_2C.C(C_2H_5)_2COCH_2COCO_2C_2H_5$ (comp. pp. 567, 609) (B. **33**, 3438).

Iodine and di-sodium acetone dicarboxylic ester produce hydroquinone tetracarboxylic ester (Vol. II.).

Condensation of acetone dicarboxylic ester and aldehydes (B. **29**, 994; R. 93; **41**, 1692, etc.).

O-Ethyl Acetone Dicarboxylic Ester, β-Ethoxyglutaconic Ester, $C_2H_5O_2C.CH$:-$C(OC_2H_5).CH_2CO_2C_2H_5$, b.p.$_{11}$ 146°, is formed from acetone dicarboxylic ester, orthoformic ester, and acetyl chloride. Hydrolysis produces at first the free *β-Ethoxyglutaconic acid*, m.p. 182° (C. 1898, II. 414).

Aqueous ammonia converts the ester into *β-Hydroxyaminoglutaminic Ester*, $RO_2C.CH_2C(OH)(NH_2).CH_2CONH_2$, and then *Glutazine, β-Aminoglutaconimide*.

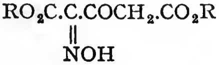


$$\overline{CO.CH : C(NH_2).CH_2CONH}$$

m.p. 300° with decomposition. This substance is converted by alcoholic ammonia into *β-Aminoglutaconic Ester*, $RO_2C.CH : (NH_2)$-CH_2CO_2R (B. **23**, 3762). Aniline at ordinary temperatures produces *Anilacetone Dicarboxylic Ester*, $C_6H_5N : C(CH_2CO_2R)_2$, m.p. 98°; whilst at 100° *Acetone Dicarboxylic Anilide*, $OC(CH_2CONHC_6H_5)_2$, is formed, together with other substances (B. **33**, 3442; **35**, 2081).

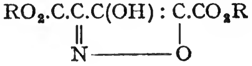
Nitrous acid converts acetone dicarboxylic esters into *Isonitrosoacetone Dicarboxylic Ester* (1) and *Hydroxyisoxazole Carboxylic Ester* (2) (B. **24**, 857); fuming nitric acid produces a *Di-isonitroso-Peroxide* (3) (B. **26**, 997):

(1)



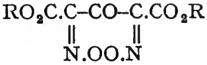
$$\begin{array}{l} RO_2C.C.COCH_2.CO_2R \\ \qquad\;\; \| \\ \qquad NOH \end{array}$$

(2)



$$\begin{array}{l} RO_2.C.C.C(OH) : C.CO_2R \\ \qquad\quad \| \qquad\qquad\quad | \\ \qquad\quad N{-}{-}{-}{-}{-}{-}O \end{array}$$

(3)

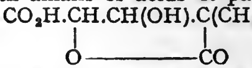


$$\begin{array}{l} RO_2C.C{-}CO{-}C.CO_2R \\ \qquad\quad \| \qquad\quad \| \\ \qquad\;\; N.OO.N \end{array}$$

The *phenylhydrazone of acetone dicarboxylic acid*, like the ester, readily **forms** the corresponding *lactazam* (*phenylpyrazolone acetic acid*) (B. **24**, 3253):

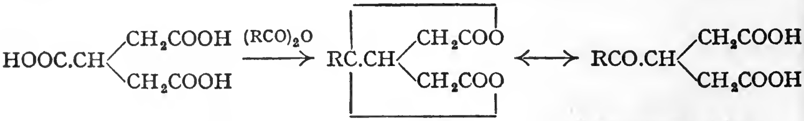
$$\begin{array}{l} C_6H_5NHN : C.CH_2CO_2H \\ \qquad\qquad\quad | \\ \quad HOOC.CH_2 \end{array} \longrightarrow \begin{array}{l} C_6H_5N.N : CCH_2CO_2H \\ \qquad | \qquad\;\; | \\ \quad CO{-}{-}CH_2 \end{array}$$

γ-Cyanacetoacetic Ester, $\mathrm{CN.CH_2CO.CH_2CO_2C_2H_5}$, b.p.$_{40}$ 135°, is formed from γ-chloracetoacetic ester and potassium cyanide (B. **24**, R. 18, 38). *γ-Cyano-dimethyl-acetoacetic Ester*, $\mathrm{CN.CH_2CO.C(CH_3)_2.CO_2CH_3}$, is formed from γ-bromo-dimethyl-acetoacetic ester. When heated with alkalis or acids it passes into *αα-Dimethyl βγ-Dihydroxyglutaric Acid Lactone*, $\begin{array}{l}\mathrm{CO_2H.CH.CH(OH).C(CH_3)_2}\\ \qquad\quad\mathrm{O}\text{————}\mathrm{CO}\end{array}$, m.p. 214° (B. **32**, 137), which, on reduction, is converted into *γ-hydroxy-dimethyl-glutaric acid lactone* (p. 559).



3. *α-Acetyl* n.*-Glutaric Acids* are prepared by the action of β-iodopropionic ester on the sodium compounds of acetoacetic ester and the alkyl acetoacetic esters: *α-Acetoglutaric Ester*, $\mathrm{RO_2C.CH(COCH_3)CH_2.CH_2.CO_2R}$, b.p. 272°; *α-Ethyl α-Acetoglutaric Ester*, $\mathrm{RO_2C.C(C_2H_5)(COCH_3).CH_2CH_2CO_2R}$, decomposes on distillation. On loss of $\mathrm{CO_2}$, the free acids pass into the corresponding δ-keto-carboxylic acids (p. 424) (A. **268**, 113). With ammonia and primary amines they form *lactams* of *δ-amino-olefine dicarboxylic mono-esters* (B. **24**, R. 660).

4. *β-Acyl Glutaric Esters* are formed when the sodium salt of tricarballylic acid (p. 593) is heated with carboxylic anhydrides, with simultaneous loss of $\mathrm{CO_2}$; they are, however, converted at the temperature of reaction into *dilactones*, from which the ketone dicarboxylic acids are regenerated by the action of alkalis (*Fittig*, A. **341**, 1):



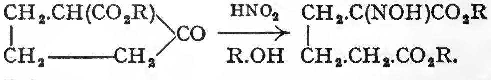
Tricarballylic Acid. Dilactone. β-Acyl Glutaric Acid.

β-Acetyl Glutaric Acid, $\mathrm{CH_3CO.CH(CH_2COOH)_2}$, m.p. 58°, is obtained from its *dilactone*, m.p. 99°, b.p.$_{12}$ 205°, by the action of boiling water or alkalis. The dilactone is formed when sodium tricarballylate is heated with acetic anhydride at 120–130°, also when acetotricarballylic ester is boiled with hydrochloric acid (A. **295**, 94).

β-Butyryl- and *β-Isobutyryl-glutaric Acid*, $\mathrm{CH_3CH_2CH_2COCH(CH_2COOH)_2}$, m.p. 88°, and $\mathrm{(CH_3)_2CHCOCH(CH_2COOH)_2}$, m.p. 100° with decomposition; *dilactones*, m.ps. 55° and 90°, are obtained from sodium tricarballylate and butyric or isobutyric anhydrides.

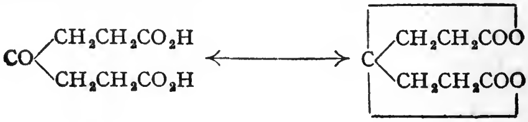
Keto-adipic, Ketopimelic and the Higher Ketone-dicarboxylic Oxides.

1. *Oximes of α-Keto-adipic Acid* and *α-Ketopimelic Acid* are obtained from adipic and pimelic esters by means of their carboxylic condensation products (comp. p. 504) when acted on by ethyl nitrite and sodium alcoholate:



α-Oximido-adipic Ester, m.p. 53°; *acid*, $\mathrm{HO_2C.CH_2CH_2CH_2C(NOH)CO_2H}$, m.p. 152° with decomposition into $\mathrm{CO_2, H_2O}$, and glutaric acid nitrile (p. 502). *α-Oximido-γ-methyl-adipic Ester*, m.p. 50°; *acid*, $\mathrm{HOOC.CH_2CH(CH_3).CH_2\text{-}C(NOH)CO_2H}$, m.p. 163° with decomposition into $\mathrm{CO_2}$, $\mathrm{H_2O}$, and β-methyl glutaric acid nitrile (p. 503). *α-Oximidopimelic Ester*, on oil; *acid*, $\mathrm{HOOC[CH_2]_4\text{-}C(NOH)CO_2H}$, m.p. 143° with decomposition into $\mathrm{CO_2}$, $\mathrm{H_2O}$, and adipic acid nitrile (p. 505) (B. **33**, 579).

2. **Acetone Diacetic Acid**, *Hydrochelidonic Acid*, *Lævulinic Acetic Acid*, *γ-Keto-pimelic Acid*, $\mathrm{CO(CH_2CH_2CO_2H)_2}$, m.p. 143°, is formed from chelidonic acid (or acetone dioxalic acid, p. 621) by reduction; also from furfuracrylic acid (Vol. II.) by cleavage with hydrochloric acid. Treatment with acetyl chloride or acetic anhydride converts it into a *dilactone*, m.p. 75°, which when boiled with water or alkalis re-forms the acid:



This dilactone is also formed during the prolonged boiling of succinic acid: $2C_4H_6O_4 = C_7H_8O_4 + CO_2 + 2H_2O$ (B. **24**, 143; A. **267**, 48; **294**, 165). Hydroxylamine produces the *oxime*, $C(NOH)(C_2H_4.CO_2H)_2$, m.p. 129° with decomposition; phenylhydrazine gives rise to the *phenylhydrazone*, $C(N_2H.C_6H_5)(C_2H_4CO_2H)$, m.p. 107°. The *Acetone Diacetic Ester* (*ethyl ester*, b.p.$_{12}$ 171°) gives, with bromine, sym.-*dibromacetone diacetic ester; methyl ester*, m.p. 58°; *ethyl ester*, m.p. 49° (B. **37**, 3295).

Phoronic Acid, Acetone Tetramethyl Diacetic Acid, $CO[CH_2.C(CH_3)_2CO_2H]_2$, m.p. 184°, is formed from the addition product of phorone and two molecules of hydrochloric acid (p. 229) by successive treatments with potassium cyanide and hydrochloric acid (B. **26**, 1173). The corresponding *γ-dilactone*, m.p. 143° (A. **247**, 110).

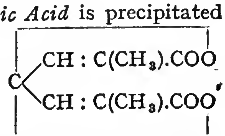
3. *Acetone Di-β-propionic Acid, δ-Keto-azelaic Acid*, $CO[CH_2CH_2CH_2CO_2H]_2$, m.p. 102° (*dimethyl ester*, m.p. 31°), is obtained from acetone dipropionic dicarboxylic ester, the product of di-sodium acetone dicarboxylic ester and two molecules of β-iodopropionic acid. Reduction changes it into sym.-*hydroxyazelaic acid*, $HOCH[CH_2CH_2CH_2CO_2H]_2$, m.p. 105°. When heated it gives off water, but instead of a dilactone (p. 570) a hexamethylene ring body is formed: *Dihydroresorcyl Propionic Acid*, $CO[CH_2]_3COCH[CH_2]_2CO_2H$. This, on cleavage with nitrous acid (comp. p. 570), yields *oximido-acetone dipropionic acid*, $HO_2C[CH_2]_3COC(NOH)[CH_2]_2CO_2H$, which undergoes the *Beckmann inversion* (p. 227), and is decomposed into glutaric and succinic acids (B. **37**, 3816).

OLEFINE- AND DI-OLEFINE-KETONE DICARBOXYLIC ACIDS

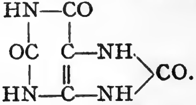
1. *Oxalocrotonic Acid*, $COOH.CO.CH_2CH:CH.CO_2H$, m.p. 190°, with formation of a di-olefine-lactone carboxylic acid, *α-Pyrone 4-Carboxylic Acid*, $CO_2H.C:CH.CH:CHCOO$, m.p. 228°, is prepared from *Oxalocrotonic Ester*, $C_2H_5O_2C.CO.CH_2CH:CHCO_2R$, m.p. 79°, which is formed by condensation of oxalic and crotonic esters by sodium alcoholate. Like oxalacetic ester, it possesses strong acidic properties (comp. Glutaconic Ester, p. 521) (C. 1901, II. 1264).

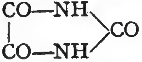
2. *α-Aceto-β-methyl-glutaconic Acid*, $CH_3CO.CH(CO_2H)C(CH_3):CHCO_2H$, is the hypothetical acid of which the *lactone* of the *aci*-form is *Isodehydracetic Acid, Dimethyl Coumalic Acid*, $CH_3C:C(CO_2H).C(CH_3):CHCO$, m.p. 155°. This is obtained by condensation of acetoacetic ester by means of sulphuric acid; also by reaction of sodium acetoacetic ester with β-chlorocrotonic ester. The lactone decomposes at 205° into CO_2 and mesitene lactone (p. 399). *Methyl ester*, m.p. 67°, b.p.$_{14}$ 167°; *ethyl ester*, m.p. 25°, b.p.$_{12}$ 166°, takes up two molecules of ammonia to form a salt which resembles ammonium carbonate in its decomposition products; at 100–140°, however, there is formed the corresponding *lactam, Carboxethyl Pseudolutidostyril*, $CH_3C:C(CO_2R)C(CH_3):CHCONH$, which is also formed by condensation of β-aminocrotonic ester (p. 419) (A. **259**, 172; B. **30**, 483).

3. *β-Carboxyl Diacrylic Acid, 3-Keto-Δ^{1,4}-pentadiëne Dicarboxylic Acid*, $CO[CH:CHCOOH]_2$, m.p. above 230°, with decomposition. Its esters are *yellow-coloured; dimethyl ester*, yellow leaflets, m.p. 169°, *diethyl ester*, yellow prisms, 50°, are formed from dibromacetone diacetic esters (above) by the loss of 2 molecules of hydrobromic acid through quinoline (B. **37**, 3293).

Carboxyl Dimethyl Acrylic Acid, Acetone Dipyroracemic Acid is precipitated from its salts in the form of its anhydride or γ-dilactone,  $C\begin{cases}CH:C(CH_3).COO\\CH:C(CH_3).COO\end{cases}$, m.p. 166°, b.p. 234°, which is obtained by the condensation of acetone and pyroracemic acid (B. **31**, 681).

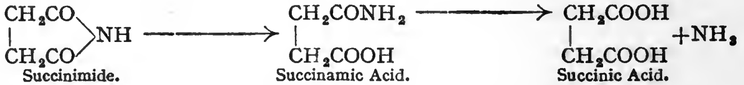
THE URIC ACID GROUP

Uric acid is a compound of two cyclic urea residues combined with a nucleus of three carbon atoms: 

By its oxidation the *ureïdes* of two dicarboxylic acids—oxalic acid and mesoxalic acid—were made known. The ureïde of a dicarboxylic acid is a compound of an acid radical with the residue, NH.CO.NH; *e.g.* 

=ureïde of oxalic acid, oxalyl urea, parabanic acid.

They are closely related to the imides of dibasic acids, succinimide (p. 497), and phthalimide; and parabanic acid may, for example, be regarded as a mixed cyclic imide of oxalic and carbonic acids. Like the imides, they possess the nature of an acid, and form salts by the replacement of the imide hydrogen with metals. The imides of dibasic acids are converted by alkalis and alkaline earths into amino-acid salts, which lose ammonia and become converted into salts of dibasic acids. Under similar conditions the ureïde ring is ruptured. At first a so-called *ur*-acid is produced, which finally breaks down into its components, urea and a dibasic acid:



Succinimide. Succinamic Acid. Succinic Acid.

Parabanic Acid. Oxaluric Acid. Oxalic Acid. Urea.

The names of a series of ureïdes having an acid character end in "uric acid,"—*e.g.* barbituric acid, violuric acid, dilituric acid. These names were constructed before the definition of the ur-acids given above, and it would be better to abandon them and use the ureïde names exclusively,—*e.g.* malonyl urea, oximidomesoxalyl urea, nitromalonyl urea, etc.

It is the purpose to discuss the urea derivatives of aldehydo- and keto-carboxylic acids, of glyoxalic acid and acetoacetic acid in connection with the ureïdes and "ur" acids of the dicarboxylic acids. These are allantoïn and methyl uracil. The first can also be prepared from uric acid, whilst the methyl uracil constitutes the parent substance for the synthesis of uric acid.

Xanthine, theobromine, theophylline, theïne or caffeïne, and guanine, hypoxanthine, adenine, etc., are related to uric acid.

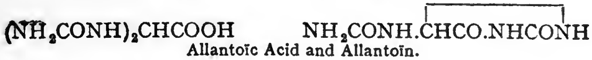
Ureïdes or Carbamides of Aldehyde- and Keto-monocarboxylic Acids.

These bodies are connected themselves with the ureïdes of the oxyacids, hydantoïn, and hydantoïc acid, which have already been discussed (p. 442).

The following compounds with urea are derived from glyoxylic acid:

$$\underbrace{OCH.CO.NHCONH_2 \qquad HOCH.CO.NH.CONH}$$

Allanturic Acid or Glyoxalyl Urea.



$$(NH_2CONH)_2CHCOOH \qquad NH_2CONH.CHCO.NHCONH$$

Allantoïc Acid and Allantoïn.

Allantoïn, $C_4H_6O_3$, m.p. 231° with decomposition, is present in the urine of sucking calves, in the allantoïc liquid of cows, and in human urine after the ingestion of tannic acid. It has also been detected in beet-juice (B. **29**, 2652). It is produced artificially on heating glyoxalic acid (also mesoxalic acid, $CO(CO_2H)_2$) with urea to 100°; also from hydantoïn by the action of bromine and urea (A. **332**, 134).

Allantoïn is formed by oxidizing uric acid with PbO_2 and MnO_2, potassium ferricyanide, or with alkaline $KMnO_4$ (B. **7**, 227). Methylated uric acids when oxidized in alkaline solutions yield *methyl allantoïns* (comp. p. 583) (A. **323**, 185).

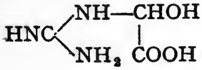
Allantoïn crystallizes in glistening prisms, which are slightly soluble in cold water, but readily in hot water and in alcohol. It has a neutral reaction, but dissolves in alkalis, forming salts.

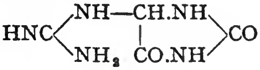
Sodium amalgam converts allantoïn into *glycoluril*, or *acetylene urea*.

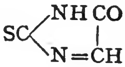
Allantoïc Acid (formula, see above) decómposes at 165°, is prepared by hydrolysis of allantoïn or its salts. It is not very soluble in water, and readily decomposes into urea and glyoxylic acid. *Ethyl ester*, $(NH_2CONH)_2CHCO_2$-C_2H_5, is prepared from glyoxylic ester, urea, and hydrochloric acid. Ammonia or alkali hydroxide solutions condense it to allantoïn (C. 1904, I. 792; 1906, II. 578).

Allanturic Acid (formula, above) is obtained when allantoïn is warmed with nitric acid, and by the oxidation of *hydantoïn* (p. 442). It is a deliquescent amorphous mass, insoluble in alcohol. *Glyoxyl Urea* (formula, see above) is a decomposition product of *oxonic acid*, $C_4H_5N_3O$, obtained by oxidation of uric acid. It consists of thick needles, readily soluble in hot water (A. **175**, 234).

Glyoxylic acid unites with guanidine to form, according to the conditions of reaction, *guanidine glyoxylic acid* (1), m.p. 210° with decomposition, or *imido-allantoïn* (2) (?) (A. **315**, 1); but with thiourea it forms *glyoxyl thiocarbimide* (3), consisting of red-brown crystals (A. **317**, 151):

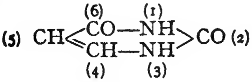
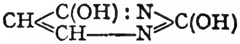
(1) 

(2) 

(3) 

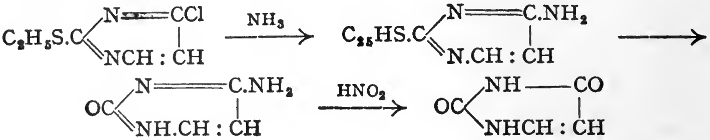
Pyruvil, $NH_2CONH.C(CH_3)CO.NHCONH$, is formed by heating pyroracemic acid and urea, during which an intermediate product, $CH_3C(NHCONH_2)_2COOH$, is formed (C. 1901, II. 1114).

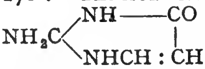
The **uracils** are the ureïdes of β-aldo- and β-keto-carboxylic acids. The simplest *uracil*, the ureïde of formyl acetic acid, its amino-derivative *cytosine*, like *thymine*, the uride of α-formyl propionic acid, together with various *purine* derivatives (p. 587), are members of the *nucleïnic acids* (see Proteins) which occur in thymus glands, fish spermatozoa, yeast, kernels of plants, etc., and obtained from these by hydrolysis with sulphuric acid. The uracils contain the six-membered *pyrimidine ring* (Vol. II.), which, when united to the five-membered *glyoxaline ring*, shows the constitutional formula of uric acid (*q.v.*). Derivatives of uracil are, therefore, employed in many ways for the synthesis of uric acid and other purine derivatives (pp. 585, *et seq*).

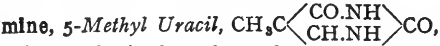
Uracil, $C_4H_4O_2N_2$.  or 

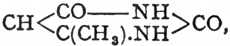
2,6-Dihydroxypyrimidine, m.p. 335° with decomposition. It is prepared from nucleïnic acid (p. 573), and synthesized (1) from hydrouracil (p. 444) by bromination to bromhydrouracil, $C_4H_5BrO_2N_2$, and withdrawal of hydrobromic acid by means of pyridine; (2) Trichloropyrimidine, $C_4HCl_3N_2$, obtained from barbituric acid (p. 576), and $POCl_3$, reacts with sodium methoxide to form dimethoxychloropyrimidine, $(C_4H(OCH_3)_2ClN_2$; this is reduced with zinc dust and hydrochloric acid to 2,6-dimethoxypyrimidine, $C_4H_2(OCH_3)_2N_2$, which is hydrolyzed to uracil by evaporation with hydrochloric acids; (3) *ψ*-Methyl thiourea and formyl acetic ester produce methyl mercapto-oxypyrimidine (comp. p. 453), which is decomposed by hydrochloric acid into methyl mercaptan and uracil (B. **34**, 3751; **36**, 3379; C. 1903, I. 1309). Uracil is easily soluble in hot water, and with difficulty in alcohol and ether. It is precipitated by phosphotungstic acid and mercuric sulphate.

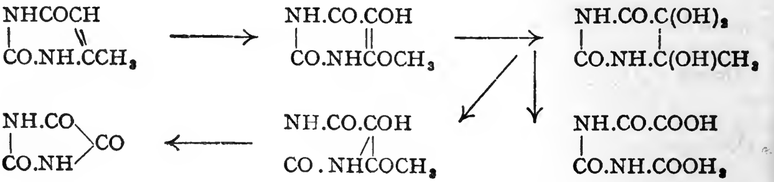
Cytosine, *Uracilimide, 2-Oxy-6-amino-pyrimidine*, $C_4H_5ON_3$ (see below), decomposed at 320–325°, is synthesized as follows: ethyl mercapto-oxypyrimidine (p. 573) and PCl_5 give ethyl mercaptochloropyrimidine, which, by ammonia, is converted into ethyl mercapto-aminopyrimidine; this is decomposed by hydrobromic acid into mercaptan and cytosine (C. 1903, I. 1309). Nitrous acid converts cytosine into uracil (C. 1903, I. 1365):


Cytosine. Uracil.

Cytosine is decomposed by permanganate into biuret (p. 445) and oxalic acid. It forms salts with nitric acid, sulphuric acid, H_2PtCl_6; also with silver, mercury, etc.; *picrate*, m.p. 278°. The isomeric *2-Amino-6-oxypyrimidine*, the *guaneïde of formyl acetic acid*,  $NH_2C\left\langle\begin{array}{l}NH\text{——}CO\\ \quad\quad\quad\quad\;|\\ NHCH:CH\end{array}\right.$, m.p. 276° with decomposition, is formed from guanidine and formyl acetic ester.

Thymine, *5-Methyl Uracil*,  $CH_3C\left\langle\begin{array}{l}CO.NH\\ CH.NH\end{array}\right\rangle CO$, m.p. 318–321° with decomposition, is synthesized analogously to the uracils: (1) from 5-methyl hydrouracil (p. 444); (2) from C-methyl barbituric acid (p. 577); (3) from 2-methyl-mercapto-5-methyl-6-oxypyrimidine, the product of *ψ*-methyl thiourea and *α*-formyl propionic ester (B. **34**, 3751; **38**, 3394; C. 1903, I. 1309).

4-Methyl Uracil,  $CH\left\langle\begin{array}{l}CO\text{——}NH\\ C(CH_3).NH\end{array}\right\rangle CO$, m.p. 320° with decomposition, is synthesized: (1) from acetoacetic ester and urea and (2) from 4-methyl hydrouracil (p. 444); $POCl_3$ reacts with methyl uracil and produces *4-methyl-2,6-dichloro-pyrimidine;* electrolytic reduction yields methyl trimethylene urea (p. 441) and 1,3-diaminobutane. Nitric acid and P_2O_5 give 5-nitro-4-methyl-uracil, and this on reduction forms *amino-methyl-uracil* (p. 585). Permanganate produces *5-oxy-methyl-uracil* and then *4,5,5-trioxy-methyl-hydrouracil* (methyl isodialuric acid). The latter, by further action of permanganate, is broken up into acetoxaluric acid; but alkalis produce *acetyl glyoxyl urea* (the ureïde of *αβ*-diketobutyric acid) which, with chromic acid, yields *parabanic acid* (p. 575).



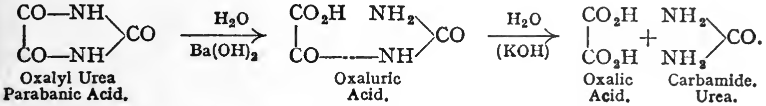
This series of oxidations and transformations probably represents the alkaline oxidation reactions of uric acid and its derivatives (comp. scheme, p. 583, and A. **333**, 144).

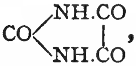
Methylation of 4-methyl uracil by means of KOH and iodomethane produces 3,4-*dimethyl uracil*, m.p. 22°, 1,4-*dimethyl uracil*, m.p. 262°, and 1,3,4-*trimethyl uracil*, m.p. 111° (A. **343**, 133, etc.).

Further uracil derivatives are obtained as intermediate compounds during the synthesis of uric acid (pp. 585, 586).

UREÏDES OR CARBAMIDES OF DICARBOXYLIC ACIDS

The most important members of this class are parabanic acid and alloxan. They were first obtained by oxidizing uric acid with nitric acid. These cyclic ureïdes by moderated action of alkalis or alkali earths are hydrolyzed and become "ur"-acids. When the action of the alkalis is energetic, the products are urea and dicarboxylic acids —*e.g.*:



Oxalyl Urea, *Parabanic Acid*,  $CO\begin{cases}NH.CO\\ \quad\;\; |\\ NH.CO\end{cases}$, m.p. 243° with decomposition, is produced by the oxidation of uric acid and alloxan with ordinary nitric acid (A. **182**, 74); by the treatment of hydantoïn (p. 442) with bromine and water (A. **333**, 115); and, synthetically, by the action of $POCl_3$ on a mixture of urea and oxalic acid; or by heating oxamide and diphenyl carbonate $CO(OC_6H_5)_2$ together at 240° (C. 1900, I. 107). It is soluble in water and alcohol, but not in ether.

Its *salts* are easily converted by water into oxalurates; *silver salt*, $C_3N_2O_3Ag_2$, is obtained as a crystalline precipitate.

Oxalyl Methyl Urea, *Methyl Parabanic Acid*, $C_3H(CH_3)N_2O_3$, m.p. 149·5°, is formed by boiling methyl uric acid, or methyl alloxan, with nitric acid, or by treating theobromine with chromic acid mixture. It is soluble in ether.

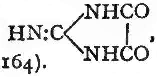
Oxalyl Dimethyl Urea, *Dimethyl Parabanic Acid, Cholestrophane*, $C_3(CH_3)_2N_2O_3$, m.p. 145°, b.p. 276°, is obtained from dimethyl alloxan and theïne by oxidation, or by heating methyl iodide with silver parabanate.

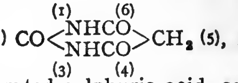
Oxaluric Acid, $NH_2CO.NHCO.CO_2H$, results from the action of alkali on parabanic acid. Free oxaluric acid is a crystalline powder, dissolving with difficulty. When boiled with alkalis or water, it decomposes into urea and oxalic acid; heated to 200° with $POCl_3$, t is again changed into parabanic acid.

The *ammonium salt*, $C_3H_3N_2O_4NH_4$, and the *silver salt*, $C_3H_3N_2O_4Ag$, crystalize in glistening needles.

The *ethyl ester*, $C_3H_3(C_2H_5)N_2O_4$, m.p. 177°, is formed by the action of ethyl odide on the silver salt, and has been synthetically prepared by allowing ethyl oxalyl chloride to act on urea.

Oxaluramide, *Oxalan*, $NH_2CO.NHCOCONH_2$, is produced on heating ethyl oxalurate with ammonia, and by fusing urea with ethyl oxamate.

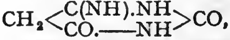
Oxalyl Guanidine,  $HN{:}C\begin{matrix}\diagup NHCO\\ |\\ \diagdown NHCO\end{matrix}$, is formed from oxalic ester and guanidine (B. **26**, 2552; **27**, R. 164).

Malonyl Urea, *Barbituric Acid,*  $(2)\ CO<\begin{matrix}\overset{(1)}{N}HC\overset{(6)}{O}\\ \underset{(3)}{N}HC\underset{(4)}{O}\end{matrix}>CH_2\ (5)$, is obtained from alloxantin by heating it with concentrated sulphuric acid, and from dibromobarbituric acid by the action of sodium amalgam. It may be synthetically obtained by heating malonic acid and urea to 100° with $POCl_3$, or by boiling urea and sodium malonic ester together in alcoholic solution (B. **37**, 3657). It crystallizes with two molecules of water in large prisms from a hot solution, and when boiled with alkalis is decomposed into malonic acid and urea. Electrolytic reduction converts it into hydrouracil and trimethylene urea (pp. 441, 444).

The hydrogen of CH_2 in malonyl urea, as in malonic ester, can be readily replaced by bromine, NO_2, and the isonitroso-group. It forms metallic salts (B. **14**, 1643; **15**, 2846).

When silver nitrate is added to an ammoniacal solution of barbituric acid, a white silver salt, $C_4H_2Ag_2N_2O_3$, is precipitated.

Malonyl Dimethyl Urea, 1,3-Dimethyl Barbituric Acid, $CH_2[CON(CH_3)]_2CO$, m.p. 123°, and *Malonyl Diethyl Urea,* m.p. 52°, are formed from malonic acid, $POCl_3$, and the respective di-alkyl urea (B. **27**, 3084; **30**, 1815).

6-Imino-isobarbituric Acid, 4-Aminouracil,  $CH_2<\begin{matrix}C(NH).NH\\ CO.{-\!-}NH\end{matrix}>CO$, is obtained in the form of needles which, when heated, form cyanacetic ester, sodium ethoxide, and urea. During the reaction cyanacetyl urea, $CN.CH_2CO.$-$NHCONH_2$, is formed as an intermediate product, which can also be prepared from cyanacetic acid, urea, and $POCl_3$ or $(CH_3CO)_2O$. *6-Imino-2-thio-barbituric Acid,* $CH_2[C_2O(NH)](NH_2)CS$, is produced from cyanacetic ester and thiourea; guanidine and this latter body form *6,2-Diiminobarbituric Acid,* $CH_2({}_2C_2ONH)$-$(NH)_2C:NH$. These substances are decomposed by dilute acids into ammonia, barbituric acid, and *2-Thiobarbituric Acid, Malonyl Thiourea,* $CH_2(CONH)_2CS$, and *2-Iminobarbituric Acid, Malonyl Guanidine,* $CH_2(CONH)_2C:NH$, respectively. These compounds are directly produced from malonic ester and thiourea or guanidine (A. **340**, 312; B. **26**, 2553). *2,4,6-Triiminobarbituric Acid, 2,4,6-Triaminopyrimidine,* $CH_2[C(NH).NH]_2C:NH$, is formed from malonic nitrile and guanidine (B. **37**, 4545). *4,4,6-Trichloropyrimidine,* $CH\leqslant(C.Cl.N)_2\geqslant CCl$, b.p. 213°, is formed from barbituric acid and $POCl_3$ at 130–145° (B. **37**, 3657). It can be converted into uracil (p. 573).

C-*Alkylated Barbituric Acids.*

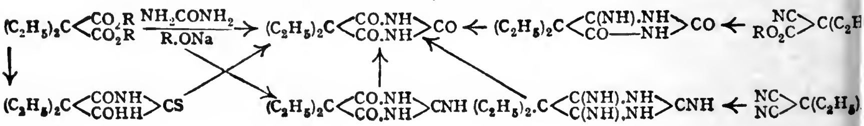
These compounds have been minutely studied on account of some of their number acting as valuble saporifics, *e.g.* C-diethyl barbituric acid (*Veronal*) and C-dipropyl barbituric acid.

Methods of formation.

(1) Alkylation (by the action of iodomethane on the silver salt of barbituric acid) only produces directly C-dimethyl barbituric acid.

(2) Malonyl guanidine (see above) is more conveniently alkylated, and the mono- and di-alkyl malonyl guanidines which are produced are converted into mono- and di-alkyl malonyl ureas when heated with acid (C. 1906, II. 1465).

(3) Condensation may occur between monomalonyl chloride (or, better, the malonic ester), monocyanacetic ester or mono-alkyl malononitrile with urea, thiourea, guanidine, or dicyandiamide, with or without the help of sodium alcoholate; C-mono-alkyl barbituric acid or its thio- and imino-derivatives (see above) are formed, which, on hydrolysis, yield the barbituric acids. The di-alkyl compounds produce the respective barbituric acid (A. **335**, 334; **340**, 310; **359**, 145; C. 1906, I. 514; II. 1465; 1695, etc.):



(4) *Dialkyl Malonuric Acids*, such as *Diethyl Malonuric Acids*, $HOOC.C(C_2H_5)_2.CO.NHCONH_2$, m.p. 162°, with decomposition; *Dipropyl Malonuric Acid*, m.p. 147° with decomposition, are formed from the malonic acid, urea, and fuming sulphuric acid. They readily decompose into CO_2 and dimethyl acetourea; the *nitriles*, on the other hand, such as $NC.C(C_2H_5)_2.CO.NHCONH_2$ (which is produced from alkyl cyanacetic ester, NaOR, and urea at ordinary temperatures) easily condense to cyclic compounds. Similarly, *Diethyl Malonyl Urethane*, $(C_2H_5)_2C(CONHCOOC_2H_5)_2$, is formed from diethyl malonyl chloride and two molecules of urethane; it is readily converted into diethyl barbituric acid by $C_2H_5.ONa$ (C. 1906, II. 574).

C-*Monomethyl Barbituric Acid*, $CH_3CH(CONH)_2CO$, m.p. 203° (B. **38**, 3394). C-*Ethyl Barbituric Acid*, m.p. 190°, unlike barbituric acid itself, is easily ethylated by iodoethane and alkalis to veronal. C-*Propyl Barbituric Acid*, m.p. 208°. C-*Isopropyl Barbituric Acid*, m.p. 216°.

C-*Dimethyl Barbituric Acid*, $(CH_3)_2C(CONH)_2CO$, m.p. 279°, is also obtained from dimethyl malonic acid, urea, and $POCl_3$; but if this treatment be applied to the homologues, only di-alkyl acetoureas, $R_2CHCO.NHCONH_2$, are produced. These acids yield stable di-sodium salts, whilst the homologous dialkyl barbituric acids only give easily hydrolyzed mono-sodium salts.

C-Diethyl Barbituric Acid, Veronal, $(C_2H_5)_2C(CONH)_2CO$, m.p. 212°, has a bitter taste, and acts as a soporific. It crystallizes from hot water in the form of colourless spear-shape crystals, and is easily soluble in alkalis and ammonia. *Thioveronal, Diethyl Malonyl Thiourea*, $(C_2H_5)_2C(CONH)_2CS$, m.p. 180°, when heated with aniline and phenylhydrazine exchanges S for the groups $:NC_6H_5$ and $NNHC_6H_5$. Reduction with sodium amalgam produces di-ethyl malonamide, $(C_2H_5)_2C(CONH_2)_2$, *Diethyl Malonyl Methylene Diamine* or *Desoxyveronal*, $(C_2H_5)_2C(CONH)_2CH_2$, m.p. 293°, and other substances (A. **359**, 154).

Tartronyl Urea, *Dialuric Acid*, $CO{<}{\scriptsize\begin{matrix}NHCO\\NHCO\end{matrix}}{>}CH.OH$, is formed by the reduction of mesoxalyl urea (alloxan) with ammonium sulphide or with zinc and hydrochloric acid, and from dibromobarbituric acid by the action of hydrogen sulphide. On adding hydrocyanic acid and potassium carbonate to an aqueous solution of alloxan, potassium dialurate separates but potassium oxalurate remains dissolved:

$$2C_4H_2N_2O_4 + 2KOH = \underset{\text{Potassium Dialurate.}}{C_4H_3KN_2O_4} + \underset{\text{Potassium Oxalurate.}}{C_3H_3KN_2O_4} + CO_2.$$

Isodialuric Acid, isomeric with dialuric acid, is prepared from oxyuracil (p. 585) and bromine water; bases easily convert it into dialuric acid,

$$CO{<}\begin{matrix}NH.CI\ (CH)\\NH.CO\text{——}\end{matrix}{>}CO \longrightarrow CO{<}\begin{matrix}NH.CO\\NH.CO\end{matrix}{>}CHOH.$$

Isodialuric acid is differentiated from dialuric acid by its more ready oxidation (A. **315**, 246).

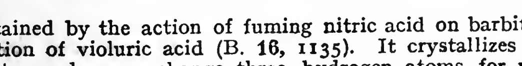
Dialuric acid crystallizes in needles or prisms, shows a very acid reaction, and forms salts with 1 and 2 equivalents of the metals (A. **344**, 1). It becomes red in colour in the air, absorbs oxygen and passes into alloxantin:

$$2C_4H_4N_2O_4 + O = C_8H_4N_4O_7 + 2H_2O.$$

Acetyl Dialuric Acid, $CH_3COOCH(CONH)_2CO$ (?), m.p. 211°, is prepared from dialuric acid and acetic anhydride. It combines with alloxan to form acetyl-alloxantin.

Tartronyl Dimethyl Urea, $HOCH[CON(CH_3)]_2CO$, m.p. 170° with decomposition (B. **27**, 3082).

Nitromalonyl Urea, Nitrobarbituric Acid, Dilituric Acid:



$$CO{<}\begin{matrix}NHCO\\NHCO\end{matrix}{>}CHNO_2, \text{ or } CO{<}\begin{matrix}NH.CO\\NH.CO\end{matrix}{>}C{:}NOOH \text{ (C. 1897, II. 266),}$$

is obtained by the action of fuming nitric acid on barbituric acid and by the oxidation of violuric acid (B. **16**, 1135). It crystallizes with three molecules of water and can exchange three hydrogen atoms for metals. *Nitromalonyl Dimethyl Urea*, m.p. 148° (B. **28**, R. 311).

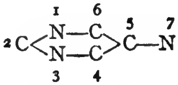
Aminomalonyl Urea, *Aminobarbituric Acid, Uramil, Dialuramide, Murexan,* $CO<^{NHCO}_{NHCO}>CHNH_2$, is obtained in the reduction of nitro- and isonitroso-barbituric acid, and also alloxan phenylhydrazone with hydriodic acid; by boiling thionuric acid with water, and by boiling alloxantin with an ammonium chloride solution. Alloxan remains in solution, whilst uramil crystallizes out. Uramil, together with alloxan, is formed in the decomposition of murexide and purpuric acid; also, when ammonium dialurate is heated (A. **333**, 71). It is only slightly soluble in hot water, and crystallizes in colourless, shining needles, which redden on exposure.

Uramil dissolves in alkalis, forming salts, but prolonged action of alkalis causes decomposition into urea and aminomalonic acid, and other bodies (A. **333**, 77). When a solution of uramil is boiled with ammonia, murexide (p. 580) is formed. Nitric acid converts uramil into alloxan. Oxidation with permanganate (A. **333**, 91). *Acetyl Uramil,* $CH_3CO.NHCH(CONH)_2CO$, is obtained from uramil and acetic anhydride; its metallic salts form well-defined crystals.

Thionuric Acid, Sulphaminobarbituric Acid, $HO_3S.NH.CH(CONH)_2CO$, and *alkyl thionuric acids* are obtained as ammonium salts from alloxan or violuric acid (below); or from alkylated alloxans and ammonium sulphite; or methyl ammonium sulphite. They are decomposed by acids into sulphuric acid and uramil or alkyl uramil. Dimethyl ammonium sulphite and alloxan yield a true bisulphite compound (see p. 579), which is decomposed into its components by acids (A. **333**, 93).

Alkyl Uramils.

In order to define the position of the alkyl groups the carbon and nitrogen atoms of uramil are numbered from 1 to 7, as is the uric acid (or purine) ring (p. 803):



7-*Methyl Uramil,* $CO(NHCO)_2CH.NHCH_3$; 1,3-*Dimethyl Uramil,* $CO[N(CH_3)\text{-}CO]_2CHNH_2$; 1,3,7-*Trimethyl Uramil* are obtained from the corresponding thionuric acids (see above); the 1,3-*Dimethyl Uramil* is also produced by methylating uramil. *Dibarbituryl Methylamine,* $CH_3N[CH(CONH)_2CO]_2$, decomposes at 280°, is formed from alloxantin and methylamine hydrochloride (J. pr. Ch. [2] **73**, 473).

5-*Methyl Uramil,* $CO(NHCO)_2C(CH_3).NH_2$, m.p. 237°, and 5-*Ethyl Uramil,* m.p. 216°, are obtained from C-alkyl barbituric acid by bromination and the action of alcoholic ammonia (A. **335**, 359).

Pseudouric Acid, Carbamido-malonyl-urea, $CO<^{NH.CO}_{NH.CO}>CH.NHCONH_2$, is produced, as an ammonium salt, from uramil and urea at 180°; as a potassium salt from uramil or murexide and potassium cyanate.

7-*Monomethyl Pseudouric Acid*; 1,3-*Dimethyl Pseudouric Acid*; 1,3,7-*Trimethyl Pseudouric Acid*; 1,3-*Diethyl Pseudouric Acid* are prepared from the corresponding alkyl uramils and potassium cyanate. When heated with oxalic acid to 150°, or when boiled with hydrochloric acid, they change into the corresponding *uric acids* (B. **30**, 559, 1823).

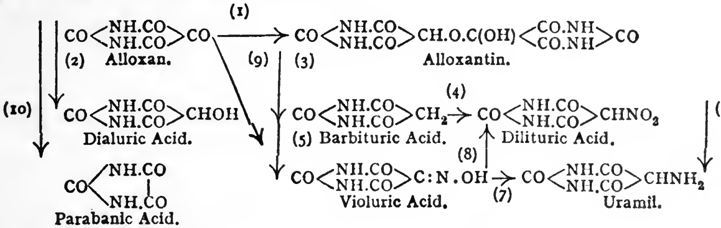
Phenyl Pseudouric Acid, $(C_4H_3O_3).NHCONHC_6H_5$, is prepared from uramil and phenyl cyanate (C. 1900, I. 806).

Thiouramil, $CO<^{NH.C(SH)}_{NH.CO}>C.NH_2$, results when a solution of potassium urate is heated with ammonium sulphide to 155–160° (B. **28**, R. 909; A. **288**, 157). It is a strong acid. Its solution imparts an orange colour to a pine chip. It gives the murexide test (p. 580). Nitric acid oxidizes it to sulphuric acid and alloxan. *β-Thiopseudouric Acid,* $CO<^{NH.C(SH)}_{NHCO}>C.NHCO.NH_2$, is obtained from thiouramil and potassium cyanate (A. **288**, 171).

Alloxan, *Mesoxalyl Urea,* $CO<^{NH.CO}_{NH.CO}>CO$, is produced by the careful oxidation of uric acid, or alloxantin, with nitric acid, chlorine, or bromine. Alloxan crystallizes from warm water in long, shining, rhombic prisms, with 4 molecules of H_2O, the crystals having the formula: $CO(NHCO)_2C(OH)_2+3H_2O$. When exposed to the air they effloresce with separation of $3H_2O$. The last molecule of water is intimately combined (p. 562), as in mesoxalic acid, and does not escape until heated to 150°.

Alloxan is easily soluble in water, has a very acid reaction, and possesses a disagreeable taste. The solution placed on the skin slowly stains it a purple red. Ferrous salts impart a deep indigo blue colour to the solution. When hydrocyanic acid and ammonia are added to the aqueous solution, the alloxan breaks down into CO_2, dialuric acid, and oxaluramide (p. 575), which separates as a white precipitate (reaction for detection of alloxan).

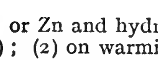
Alloxan is the parent substance for the preparation of numerous derivatives (*Baeyer*, A. **127**, 1, 199; **130**, 129), which have in part already received mention, and some of which will be discussed after alloxan. These genetic relationships are expressed in the following diagram:

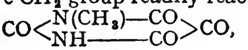


(1) Reducing agents, *e.g.* hydriodic acid, $SnCl_2$, H_2S, or Zn and hydrochloric acid, convert alloxan in the cold into *alloxantin* (p. 580); (2) on warming, into *dialuric acid* (p. 577). (3) Alloxantin digested with concentrated sulphuric acid becomes *barbituric acid* (p. 576); (4) fuming nitric acid changes it to *dilituric acid;* (5) and with potassium nitrite it yields *violuric acid.* (6) (7) Uramil results from the reduction of dilituric acid and violuric acid. (8) Dilituric acid is formed when violuric acid is oxidized. (9) Hydroxylamine converts alloxan into its oxime—violuric acid. (10) Boiling dilute nitric acid oxidizes alloxan to parabanic acid and CO_2.

The primary alkali sulphites unite with alloxan just as they do with mesoxalic acid, and crystalline compounds are obtained, *e.g.* $C_4H_2N_2O_4.KHSO_3+H_2O$. Pure alloxan can be preserved without undergoing decomposition, but in the presence of even minute quantities of nitric acid it is converted into alloxantin. Alkalis or calcium or barium hydroxide change it to alloxanic acid, even when acting in the cold. Its aqueous solution undergoes a gradual decomposition (more rapid on heating) into alloxantin, parabanic acid, and CO_2.

Alloxan Phenylhydrazone, m.p. 284° (B. **24**, 4140; **31**, 1972).

Alloxan Semicarbazide (B. **30**, 131). Alloxan unites with aromatic amines to form dyes of *quinonoid* character (Vol. II.) (A. **333**, 36; J. pr. Ch. [2] **73**, 449). o-Phenylene diamine produces *Alloxazine*,  $C_6H_4\left\langle\begin{matrix}N{=}C.CO.NH\\ |\qquad\ \ |\\ N{=}C.NH.CO\end{matrix}\right.$. Substances with an active CH_2-group readily react with alloxan (A. **255**, 230, etc.).

Methyl Alloxan,  $CO\left\langle\begin{matrix}N(CH_3){-}CO\\ NH{-\!-\!-}CO\end{matrix}\right\rangle CO$, is produced by the oxidation of methyl uric acid.

Dimethyl Alloxan, $CO[N(CH_3).CO]_2CO$, is produced when aqueous chlorine (from hydrochloric acid and $KClO_3$) acts on theïne; and by the careful oxidation of tetramethyl alloxantin (B. **27**, 3082). When it is boiled with nitric acid, methyl and dimethyl parabanic acid are formed.

Diethyl Alloxan, B. **30**, 1814.

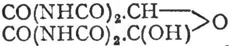
Dibromomalonyl Urea, Dibromobarbituric Acid, $Br_2C(CONH)_2CO$, results when bromine acts on barbituric acid, nitro-, amido- and isonitroso-barbituric acids.

Oximidomesoxalyl Urea, *Isonitrosobarbituric Acid, Violuric Acid*, $CO(NHCO)_2$-C:NOH, the oxime of alloxan, the first known "ketoxime," is obtained by the action of potassium nitrite on barbituric acid, and of hydroxylamine on alloxan. It unites with metals to form blue, violet, or yellow coloured salts (B. **32**, 1723). When heated with the alkalis, it breaks down into urea and isonitrosomalonic acid (p. 563). *Oximidomesoxalyl Dimethyl Urea*, m.p. 141° (B. **28**, 3142; R. 912). *Diethyl Violuric Acid* (B. **30**, 1816).

Alloxanic Acid, $NH_2.CO.NH.CO.CO.CO_2H$. If barium hydroxide solution be added to a warm solution of alloxan as long as the precipitate which forms continues to dissolve, barium alloxanate, $C_4H_2N_2O_5Ba+4H_2O$, will separate out in needles when the solution cools. To obtain the free acid, the barium salt is decomposed with sulphuric acid and the liquid is evaporated at a temperature of 30–40°, whereby a mass of crystals is obtained. Water dissolves them easily. Alloxanic acid is a dibasic acid, inasmuch as both the hydrogen of carboxyl and of the imide group can be replaced by metals. When the salts are boiled with water, they decompose into urea and mesoxalates (p. 562).

Diureïdes.—When the ureïdes, parabanic acid, alloxan and dimethyl alloxan are reduced, there is probably combination of the reduced with the still unreduced molecules (see Vol. II., Quinhydrone), whereby the diureïdes, oxalantin, alloxantin and amalic acid are formed (comp. A. **333**, 63; **344**, 17).

Oxalantin, *Leucoturic Acid*, $C_6H_6N_4O_6$, is obtained by the reduction of parabanic acid.

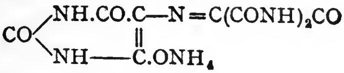
Alloxantin,  $\begin{matrix}CO(NHCO)_2.CH—\\CO(NHCO)_2.C(OH)\end{matrix}\!\!>\!O+3H_2O$ (?), is obtained (1) by reducing alloxan with $SnCl_2$, zinc and hydrochloric acid, or H_2S in the cold; (2) by mixing solutions of alloxan and dialuric acid; (3) from uric acid and dilute nitric acid (A. **147**, 367); (4) from convicin, a substance occurring in broad beans, *Vicia faba minor*, and in vetches, *Vicia sativa*, when they are heated with sulphuric or hydrochloric acid (B. **29**, 2106). It crystallizes from hot H_2O in small, hard prisms with $3H_2O$ and turns red in an atmosphere containing ammonia. Its solution has an acid reaction; ferric chloride and ammonia give it a deep blue colour, and barium hydroxide solution produces a violet precipitate, which on boiling is converted into a mixture of barium alloxanate and dialurate. On boiling alloxantin with dilute sulphuric acid, it changes into the ammonium salt of *Hydurilic Acid*, $C_8H_6N_4O_6+2H_2O$. It combines with cyanamide, forming *Isouric Acid*, NC.NHCH$(CONH)_2$CO, which yields uric acid when boiled with hydrochloric acid, and *γ-thiopseudouric acid*, $H_2N.CS.NHCH(CONH)_2CO$, when heated with ammonium sulphide (B. **38**, 2563).

Tetramethyl Alloxantin, *Amalic Acid*, $C_8(CH_3)_4N_4O_7$, is formed by the action of nitric acid or chlorine water on theïne, or, better, by the reduction of dimethyl alloxan (see above) with hydrogen sulphide (A. **215**, 258).

Purpuric Acid, $C_8H_5N_6O_5$, is prepared from murexide (the salt of this acid) by passing hydrochloric acid gas into its solution in glacial acetic acid. It is an orange-red powder, which is immediately decomposed into alloxan and uramil by the action of water (J. pr. Ch. [2] **73**, 463).

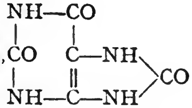
Murexide, $C_8H_4N_6O_5(NH_4)+H_2O$ (structural formula, see below), is the *ammonium salt of purpuric acid*. It is formed (1) from alloxantin and ammonium acetate and carbonate when they are heated; (2) by mixing alloxan and uramil in ammoniacal solution; (3) by careful oxidation of uric acid with dilute nitric acid (see above, Alloxantin) and adding ammonia to the residue on evaporation (*murexide reaction*, C. 1898, I. 665; A. **333**, 28). It forms tables or prisms of a gold-green colour, which dissolve in water to a purple-red coloured solution. *Sodium Purpurate*, $C_8H_4N_6O_5Na+H_2O$, is formed from murexide and sodium chloride; *potassium purpurate* also from the di-potassium salt of uramil and iodine.

Hydrochloric acid decomposes murexide partially into uramil and alloxan, and partly into ammonia and alloxantin. 1,3-Dimethyl uramil and alloxan, also 1,3-dimethyl alloxan and uramil, give two different murexides, showing that the molecule is an unsymmetrical one. 5-Alkyl uramils (p. 578) do not yield a murexide; 7-alkyl uramils lose alcohol and form salts of a simple purpuric acid; therefore, purpuric acid is considered to be aci-*barbituryl imidoalloxan*, and murexide, the ammonium salt to have the formula:



$$\mathrm{CO}\begin{array}{l}\diagup \mathrm{NH.CO.C{-}N{=}C(CONH)_2CO}\\ \qquad\qquad\quad\ \ \| \\ \diagdown \mathrm{NH{-}{-}C.ONH_4}\end{array}$$

(A. **333**, 22; C. 1904, II. 316; J. pr. Ch. [2] **73**, 499).

Uric Acid, $C_5H_4N_4O_3$,  is a white, crystalline, sandy powder, discovered by *Scheele* in 1776, in urinary calculi. It occurs in the fluids of the muscles, in the blood and in the urine, especially of the carnivoræ, whilst that of the herbivoræ contains mostly hippuric acid; also, in the excrements of birds (guano), reptiles, and insects. When urine is exposed for a while to the air, uric acid separates; this also occurs in the organism (formation of gravel and joint concretions) in certain abnormal conditions.

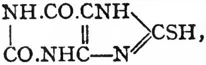
History (B. **32**, 435).—*Liebig* and *Wöhler* (1826) showed that numerous derivatives could be obtained from uric acid. Their relationships and constitution were chiefly explained by *Baeyer* in 1863 and 1864. In consequence of certain experiments of *A. Strecker*, *Medicus* (1875) proposed the structural formula given above for the acid. This was conclusively proved by *E. Fischer* in his investigation of the methylated uric acids.

The results derived from analysis were confirmed by the synthesis made in 1888 by *R. Behrend* and *O. Roosen*, who proceeded from acetoacetic ester and urea (p. 585). *Horbaczewski* (1882–1887) had previously made syntheses of uric acid at elevated temperatures, but obtained poor yields. They consisted in melting together glycocoll, trichlorolactamide, etc., with urea. No clue as to the constitution of the acid could be deduced from these. In 1895 *E. Fischer* and *Lorenz Ach* showed how pseudouric acid (p. 578), previously synthesized by *A. Baeyer*, could, by fusion with oxalic acid, be converted into uric acid.

Preparation.—Uric acid is best prepared from guano or the excrements of reptiles.

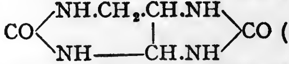
Properties.—Uric acid is a shining, white powder. It is odourless and tasteless, insoluble in alcohol and ether, and dissolves with difficulty in water; 1 part requires 88,000 parts of water at 18° (C. 1900, II. 42) for its solution, and 1800 parts at 100°. Its solution remains long supersaturated. Its solubility is increased by the presence of salts like sodium phosphate and borate. Water precipitates it from its solution in concentrated sulphuric acid (B. **34**, 263). On evaporating uric acid to dryness with nitric acid, a yellow residue is obtained, which assumes a purple-red colour if moistened with ammonia, or violet with potassium or sodium hydroxides (murexide reaction p. 580). When heated, uric acid decomposes into NH_3, CO_2, urea and cyanuric acid. The action of chloride and oxychloride of phosphorus on uric acid and alkyl uric acids is of special importance in the chemistry of the uric acid group. The reaction is comparable to the conversion of acid amides into imidochlorides. The resulting compounds are highly reactive, whereby the chlorine can be exchanged for alkoxyl, hydroxyl, hydrosulphyl, the amino-group, iodine, and sometimes also hydrogen. The inter-connection between the members of the uric acid group can be elucidated by these chemical changes (B. **32**, 445).

Carbon disulphide, when heated under pressure with uric acid, forms with it *Thioxanthine*



$$\left.\begin{array}{l} NH.CO.CNH \\ |\qquad\quad \| \\ CO.NHC{-}N \end{array}\right\rangle CSH$$

, which also results when γ-thiopseudouric acid (p. 580) is boiled with mineral acids (C. 1902, I. 548; B. **34**, 2563). When heated with ammonium sulphide urea is converted into thiouramil (p. 578). Electrolytic reduction in sulphuric acid solution produces *Purone*

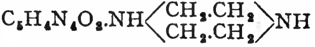


$$CO\left\langle\begin{array}{l} NH.CH_2.CH.NH \\ \qquad\qquad\ | \\ NH{-}{-}CH.NH \end{array}\right\rangle CO$$

(?) a neutral body, together with the isomeric *isopurone*, soluble in alkalis and acids, which can also be produced by the transformation of *purone*, and also *tetrahydrouric acid*, $C_5H_8N_4O_3$. Similar products are also obtained from the methylated uric acids (below) (B. **34**, 258). Formaldehyde unites with uric acid to form *mono-* and *di-formaldehyde uric acid* (A. **299**, 340).

Salts.—Uric acid is a weak dibasic acid. It forms hydrogen salts with the alkali carbonates. The normal alkali salts are obtained by dissolving the acid in potassium or sodium hydroxide. When CO_2 is conducted through the alkaline solution, the primary salts are precipitated.

The *potassium salt*, $C_5H_3N_4O_3K$, dissolves in 800 parts of water at 20°; the *sodium* and *ammonium salts* are more insoluble; *lithium salt* (*Lipowitz*) is much more soluble (in 368 parts of water at 19°) (A. **122**, 241), hence lithium mineral waters are used in such diseases where there is an excessive secretion of uric acid. This salt is, however, greatly surpassed by the *piperazine salt*,

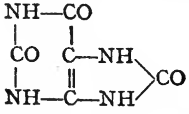


$$C_5H_4N_4O_3.NH\left\langle\begin{array}{l} CH_2.CH_2 \\ CH_2.CH_2 \end{array}\right\rangle NH$$

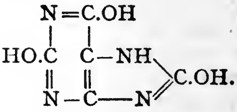
(*Finzelberg*), which dissolves in 50 parts of water at 17° (B. **23**, 3718). The *lysidine* or the *methyl glyoxalidine salt* (*Ladenburg*) is even more soluble (one part in 6 parts of water; B. **27**, 2952).

Methyl Uric Acids (B. **32**, 2721; A. **309**, 260).—The four hydrogen atoms in uric acid can be replaced by methyl. In all methyl uric acids, including tetramethyl uric acid, the methyl groups are linked to nitrogen; this, in conjunction with the decompositions and synthesis of uric acid, argues for formula I., without, however, in the light of our present representations, excluding formulæ such as II. (comp. below, the isomeric 3-methyl uric acids):

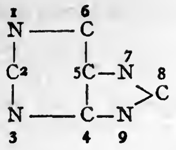
I.

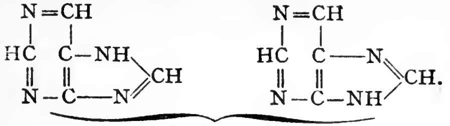


II.



To indicate the position of the methyl groups in the methyl uric acids and the constitution of other bodies containing the same hetero-twin ring, *E. Fischer* suggested that the carbon and nitrogen atoms of the nucleus contained in uric acid and bodies related to it be numbered, and that the hydrogen compound of the nucleus, C_5N_4, which could have two formulæ, should be called "*purine*" (from *purum* and *uricum*):

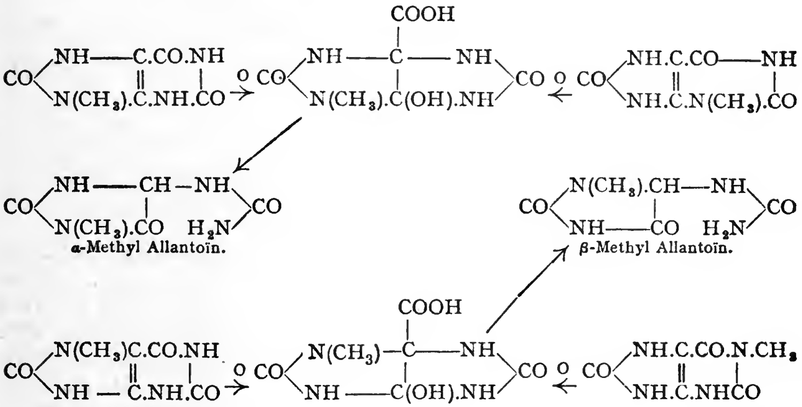




Purine (B. 32, 449).

The methyl uric acids are obtained (1) by treatment of lead and potassium urates and methyl urates with iodomethane; (2) from the formaldehyde uric acid compound (p. 582) by reduction (C. 1900, II. 459); (3) from the corresponding pseudouric acid (p. 578) through loss of water. Whilst formula I. for uric acid indicates the possibility of only four isomeric monomethyl uric acids, actually six are known, as well as six dimethyl uric acids, four trimethyl uric acids and one tetramethyl uric acid.

9-*Methyl Uric Acid* (β) and 3-*Methyl Uric Acid* (α) are formed from uric acid. The former yields alloxan, the latter methyl alloxan, when treated with nitric acid; both are converted into glycocoll when heated with hydrochloric acid. 7-*Methyl Uric Acid* (γ) is formed from 7-methyl pseudouric acid (p. 578). δ-*Methyl Uric Acid*, prepared from 1,4-dimethyl uracil (A. **309**, 260) and ζ-*methyl uric acid*, prepared by methylating uric acid in a weak acetic acid solution are both different from α-methyl uric acid, although they contain the methyl group in the 3-position. 1-*Methyl Uric Acid* (ε-) is also formed from monomethyl alloxan (B. **32**, 2721). The 3-methyl uric amides (α, δ, and ζ) when oxidized with permanganate, give rise to the same α-methyl allantoïn as it obtained from 9-methyl uric acid. Similarly, 1- and 7-methyl uric acid yield the same β-methyl allantoïn, which can be explained by the assumption of the existence of a common, symmetrical intermediate compound (A. **333**, 145):



α-Methyl Allantoïn.

β-Methyl Allantoïn.

3,9-*Dimethyl Uric Acid* (α) is obtained from basic lead urate and iodomethane. 7,9-*Dimethyl Uric Acid* (β) (B. **17**, 1780). 1,3-*Dimethyl Uric Acid* (γ), is prepared from 1,3-dimethyl pseudouric acid (p. 578); and from 1,3-dimethyl 4,5-diaminouracil (see also Theophyllin, p. 590). 3,7-*Dimethyl Uric Acid* (δ) is formed from 7-methyl uric acid (see also Theobromine, p. 589). 1,7-*Dimethyl Uric Acid* is produced from 1,7-Dimethyl Uric Acid, 1,9-*Dimethyl Uric Acid* (B. **32**, 464).

1,3,7-*Trimethyl Uric Acid*, prepared from 1,3,7-trimethyl pseudouric acid (α), is identical with hydroxycaffeïne (B. **30**, 567). 3,7,9-*Trimethyl Uric Acid* (α) is formed from 7,9-dimethyl uric acid. 1,3,9-*Trimethyl Uric Acid* is produced from 1,3-dimethyl uric acid. 1,7,9-*Trimethyl Uric Acid* (B. **32**, 466).

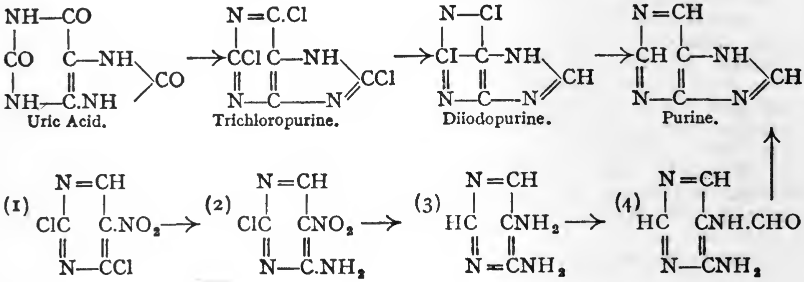
Tetramethyl Uric Acid is prepared from potassium trimethyl urate and iodomethane. Isomeric with it is *methoxycaffeïne*, 1,3,7-*trimethyl* 2,6-*dioxy*-8-*methoxy*-

purine, which is prepared from bromo- or chloro-caffeïne by the action of sodium hydroxide in methyl alcohol (B. **32**, 467).

Phenyl Uric Acid is prepared from phenyl pseudouric acid (p. 578) (C. 1900, I. 806).

Purine, $C_5N_4H_4$, m.p. 216°, is the fundamental compound of the uric acid group (p. 583). It cannot be obtained directly from uric acid, but is prepared by converting uric acid by $POCl_3$ (p. 581) into *trichloropurine*, which, with hydriodic acid at 0°, gives 2,6-*diodopurine*; this, on reduction with zinc dust and water results in purine.

Purine, like uric acid, can also be synthesized as follows:—synthetic methyl uracil is converted into 5-nitrouracil (p. 585); this, with $POCl_3$, yields 2,4-dichloro-5-nitropyrimidine (1), which with ammonia gives 2 chloro-4-amino-5-nitropyrimidine (2); reduction with hydriodic acid gives 4,5-diaminopyrimidine (3), of which the formyl-derivative (4), obtained by the action of formic acid, is decomposed when heated with water, when purine is formed:

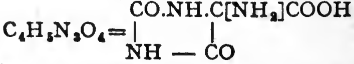


Purine reacts simultaneously as an acid and as a strong base. It is easily soluble in water, and is stable towards oxidizing agents.

Methyl Purines and other simple purine derivatives are obtained similarly (B. **31**, 2550; **39**, 250).

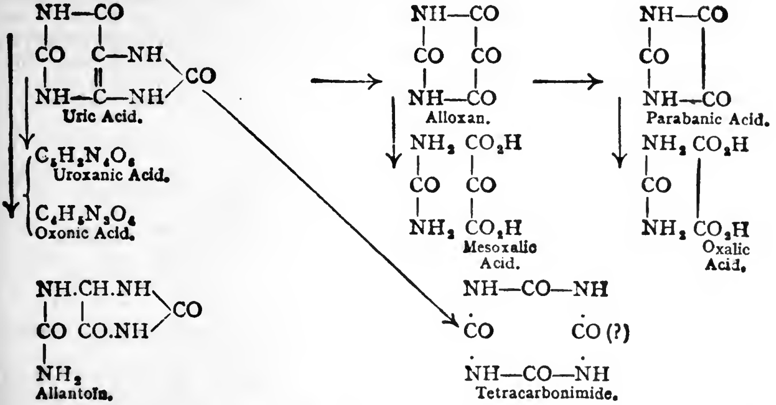
OXIDATION OF URIC ACID

Mesoxalyl urea or alloxan and oxalyl urea or parabanic acid are produced when uric acid is oxidized with nitric acid. When the acid is carefully oxidized either with cold nitric acid or with potassium chlorate and hydrochloric acid, it yields mesoxalyl urea and urea. Allantoïn is produced when potassium permanganate, or iodine in potassium hydroxide, acts on the acid (B. **27**, R. 902). Hydrogen peroxide converts sodium urate into *tetracarbonimide*, $C_4H_4N_4O_4$, a weak tetrabasic acid (B. **34**, 4130). When air or potassium permanganate acts on the alkaline solution of uric acid (B. **27**, R. 887; **28**, R. 474), allantoïn is formed together with *uroxanic acid*, *diureïdomalonic acid*, $C_5H_8N_4O_6=(NH_2CONH)_2C(COOH)_2$ (?) (comp. A. **333**, 151). From this alkali produces *oxonic acid*, *aminohydantoïn carboxylic acid*,



$$C_4H_5N_3O_4=\begin{array}{l}CO.NH.C[NH_2]COOH\\ |\qquad\qquad\quad |\\ NH - CO\end{array}$$

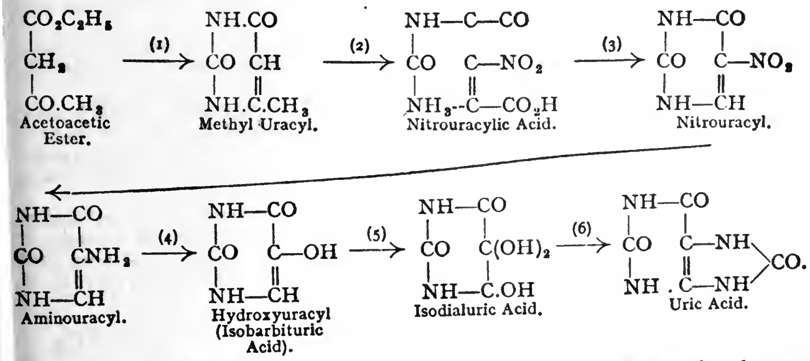
(?). For the course of these oxidation reactions compare the scheme of oxidation of the methyl uric and to the methyl allantoïns (p. 583), and of methyl uracil (p. 574). These reactions suggest the following diagram, in which the breaking-down of alloxan and parabanic acid is considered:



Uric acid is the diureïde of the hypothetical body, $CO{=}C(OH).CO_2H$, or $C(OH)_2{=}C(OH){-}CO_2H$, the pseudo-form of the half-aldehyde of mesoxalic acid, $CHO.CO.CO_2H$, (p. 545).

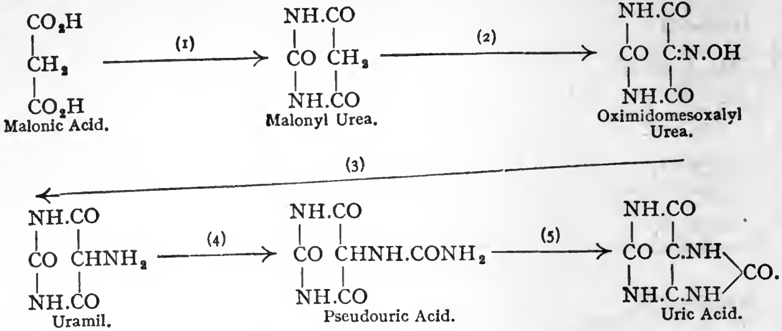
SYNTHESIS OF URIC ACID: (1) FROM ACETOACETIC ESTER: (2) FROM MALONIC ACID: (3) CYANACETYL UREA

(1) **From Acetoacetic Ester:** (1) Acetoacetic ester and urea unite to *β-uramidocrotonic ester*. When this is hydrolyzed with alkali it yields an acid which, in a free state, splits off water and becomes a cyclic ureïde—*methyl uracyl.* (2) Nitric acid converts the latter into *nitrouracyl carboxylic acid,* (3) whose potassium salt when boiled with water loses a molecule of carbon dioxide, and becomes converted into the potassium salt of *nitrouracyl.* (4) The reduction of the latter with tin and hydrochloric acid gives in part *aminouracyl* (A. 309, 256) and in part hydroxyuracyl or *isobarbituric acid.* (5) Bromine water oxidizes the latter to *isodialuric acid,* which when heated (6) with urea and sulphuric acid yields *uric acid* (A. 251, 235).



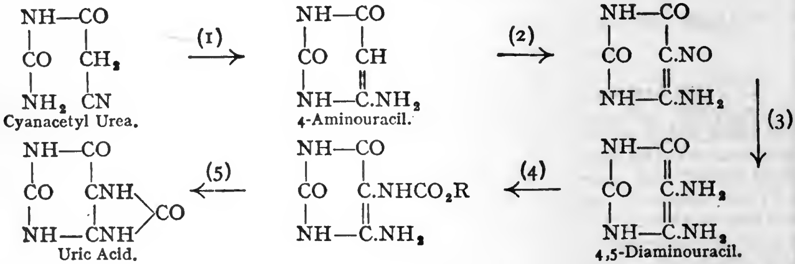
(2) **From Malonic Acid:** (1) Urea and malonic acid yield malonyl urea, which (2) nitrous acid converts into oximidomesoxalyl urea or violuric acid. (3) When the latter is reduced, amidomalonyl urea or uramil results. (4) This is changed by potassium cyanate into pseudouric acid. (5) On withdrawing water

from pseudouric acid by means of molten oxalic acid or boiling hydrochloric acid, *uric acid* results (B. **30**, 559):



Since alloxan and dimethyl alloxan yield methylated pseudouric acids, methylated uric acids can also be synthesized in this way.

(3) From **Cyanacetyl Urea**: Urea and cyanacetic acid are condensed to (1) cyanacetyl urea, and this to (2) 4-aminouracil or 4-amino-2,6-dioxypyrimidine (C. 1906, II. 1590; B. **41**, 532). This, with nitrous acid, gives (3) a nitroso-compound which, with ammonium sulphide, is reduced to (4) 4,5-diaminouracil. The diamine reacts with chlorocarbonic ester and aqueous sodium hydroxide to form (5) a urethane, the sodium compound of which when heated to 180–190° is converted into (6) sodium urate (*W. Traube*, B. **33**, 3035; A. **331**, 64):



This synthesis can be generally employed, with the following modifications:—

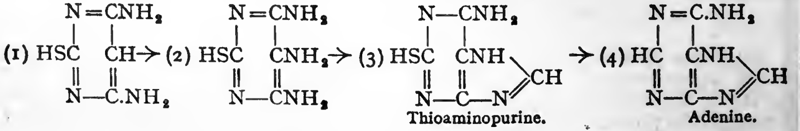
(1) Replacement of the urea by methylated ureas in the condensation with cyanacetic acid to obtain *methylated uric acids*.

(2) Replacement of the chlorocarbonic ester by formic acid; formyl diaminouracil is formed, the sodium compound of which, on being heated, yield *xanthine* or *methylated xanthines* (p. 587).

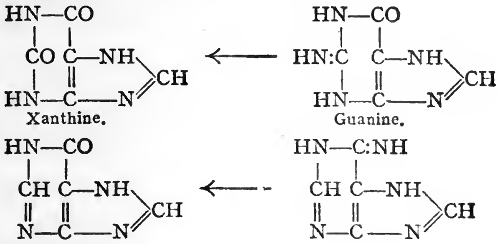
(3) Condensation of guanidine, instead of urea, with cyanacetic acid to form 2,4,6-diamino-oxypyrimidine; this is ultimately transformed into guanine (p. 587).

(4) Condensation of cyanacetic acid with thiourea to form 2-thio-4-amino-6-oxypyrimidine. This is converted into thio-oxypurine which, when oxidized by nitric acid, yields sulphuric acid and *hypoxanthine* (p. 588).

(5) Condensation of malonic nitrile with thiourea to form 2-thio-4,6-diaminopyrimidine (below), which, analogously to the above, is converted through its nitrous compound into 2-thio-4,5,6-triaminopyrimidine (2), of which the potassium salt of the formyl-compound, when heated yields 2-thio-6-aminopurine (3); oxidation with H_2O_2 produces sulphuric acid and *adenine* (4):



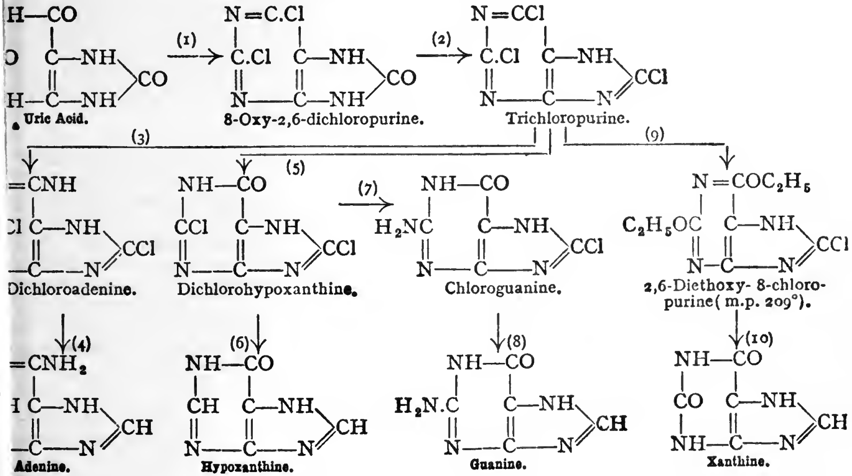
Xanthine Group.—Guanine, xanthine, hypoxanthine, and adenine stand in close relation to uric acid. Like it, they occur as products of the metabolism of the animal organism, and are most easily produced from *nucleïnic* acids (p. 573) by boiling them with water (comp. B. **37**, 708). Xanthine and hypoxanthine occur in the extract of tea. Bodies of the xanthine group are found in the juice of the sugar beet (B. **29**, 2645).


Xanthine. Guanine.
Hypoxanthine. Adenine.

Guanine is changed into xanthine by the action of nitrous acid and yields guanidine on decomposition (p. 455). It is, therefore, to be regarded as being xanthine in which a guanidine residue takes the place of a urea residue, *i.e.* the oxygen of a CO-group is replaced by NH. ***Adenine*** stands in similar relation to hypoxanthine as guanine to xanthine, in that its conversion into hypoxanthine is brought about by nitrous acid.

CONVERSION OF URIC ACID INTO XANTHINE, GUANINE, HYPOXANTHINE AND ADENINE

Potassium urate and phosphorus oxychloride produce 8-*oxy*-2, 6-*dichloropurine*, which on further treatment with phosphorus oxychloride yields 2, 6, 8-*trichloropurine*, m.p. 188°. The latter is a weak acid, and gives, on methylation, a mixture of the two isomeric forms of methyl trichloropurine.

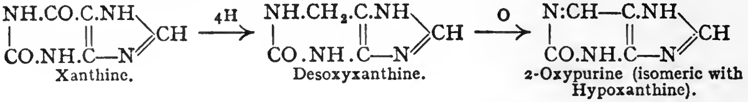

Uric Acid. 8-Oxy-2,6-dichloropurine. Trichloropurine.
Dichloroadenine. Dichlorohypoxanthine. Chloroguanine. 2,6-Diethoxy- 8-chloropurine (m.p. 209°).
Adenine. Hypoxanthine. Guanine. Xanthine.

The chlorine atoms 2 and 6 are easily substituted in the presence of alkalis by OH, C_2H_5O, and NH_2; but in the 8-position the chlorine atom can be replaced by fuming hydrochloric acid, but not by alkalis. On this behaviour is based the synthesis of xanthine, guanine, hypoxanthine and adenine (B. **30**, 2220, 2226).

Uric acid is (1) acted on by $POCl_3$ to form 8-*oxy-2,6-dichloropurine*, and is similarly (2) converted into *trichloropurine*. The latter, with aqueous ammonia at 100° gives (3) *dichloradenine*, with aqueous KOH at 100° (5) *dichlorohypoxanthine*, and with sodium ethoxide (9), 2,6-*dimethoxy-8-chloropurine*. These three substances, when reduced with hydriodic acid yield (4) *adenine*, (6) *hypoxanthine*, and (10) *xanthine*. Further, dichlorohypoxanthine and alcoholic ammonia (7) yield *chloroguanine*, and this, with hydriodic acid, (8) *guanine*.

For the synthetic preparation of these four substances see p. 586, scheme 3, for the synthesis of uric acid.

Xanthine and the methylated xanthines (p. 589) are reduced electrolytically in sulphuric acid solution, whereby the oxygen atom in position 6 is replaced by two hydrogen atoms to form the *desoxy*-compound, which easily loses two hydrogen atoms by oxidation to form *oxypurine*. Similarly, guanine yields *desoxyguanine* and this 2-*aminopurine*, similarly with adenine (*Tafel*, B. **33**, 3369; **34**, 1165):



Xanthine. Desoxyxanthine. 2-Oxypurine (isomeric with Hypoxanthine).

Desoxyxanthine, *desoxyheteroxanthine*, and *desoxyparaxanthine* are decomposed by acids into CO_2, NH_3 and amino-methyl-imidazolone:

whilst *desoxytheophylline* and *desoxycaffeïne*, xanthines, in which the methyl group occupies the 3-position, are far more stable (B. **41**, 2546).

Xanthine, 2,6-*Dioxypurine*, $C_5N_4H_4O_2$ (constitutional formula, above), occurs in small quantities in animal secretions, such as urine, blood, the liver, and sometimes in urinary calculi; it is found, also, in extract of tea. It is prepared by the action of nitrous acid on guanine in sulphuric acid solution (B. **32**, 468); also, by heating the sodium salt of formyl-4,5-diaminouracil (p. 586) to 220°. It forms a white amorphous mass, which is somewhat soluble in boiling water, and combines with both acids and alkalis. It dissolves easily in boiling ammonia, from a solution in which silver nitrate precipitates a compound, $C_5H_2Ag_2N_4O_2+H_2O$. The corresponding lead compound is converted into theobromine (dimethyl xanthine) when heated with iodomethane at 100°. Methylation in alkaline aqueous solutions produces caffeïne. When heated with potassium chlorate and hydrochloric acid, xanthine (analogously to caffeïne, p. 590) is broken down into alloxan and urea.

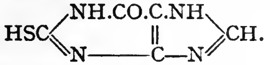
8-*Thioxanthine*,  $\begin{array}{l}CO.NH.C.NH\diagdown\\ |\qquad\quad\ \ \|\qquad\quad >SC\\ NH.CO.C.NH\diagup\end{array}$, is formed when γ-thiopseudouric acid (p. 579) is heated; and from 4,5-diaminouracil (p. 586), and carbon disulphide (C. 1903, II. 80).

Guanine, 2-*Amino-6-oxypurine*, $C_5N_5H_5O$ (constitutional formula, p. 587), occurs in the pancreas of some animals, and particularly in guano; also in the silvery matter of the scales of bleak (connected with the dace), *Alburnus lucidus* (C. 1898, I. 1132). It is readily synthesized by converting cyanacetyl guanidine (p. 586) into *triamino-oxypyrimidine*,  $H_2N.C\begin{array}{l}\diagup NH.CO.C.NH_2\\ \qquad\qquad\quad\ \|\\ \diagdown N\text{———}CNH_2\end{array}$, and heating this with formic acid (B. **33**, 1371).

Guanine forms an amorphous powder, insoluble in water, alcohol and ether. It combines with one and two equivalents of acids forming crystalline salts, such as $C_5H_5N_5O.2HCl$; and also with alkalis to form crystalline compounds. Silver nitrate precipitates a crystalline compound, $C_5H_5N_5O.AgNO_3$, from a nitric acid solution of the substance. Nitrous acid converts guanine into xanthine. Potassium chloride and hydrochloric acid decompose it into parabanic acid, guanidine and carbon dioxide (p. 455).

Bromoguanine is formed from guanine and bromine. Fuming hydrochloric acid converts it into 2-*Amino*-6,8-*dioxypurine*. *Chloroguanine* is prepared from dichlorohypoxanthine and alcoholic ammonia. With hydriodic acid it yields guanine.

Hypoxanthine, 6-*Oxypurine*, $C_5N_4H_4O$ (constitutional formula p. 587) almost invariably accompanies xanthine in the animal organism, and can be differentiated from it particularly by the slight solubility of its hydrochloride. It forms needles, soluble with difficulty in water, but soluble in acids and alkalis, and in ammoniacal solution is precipitated by silver nitrate which forms $C_5H_2Ag_2N_4O + H_2O$. *Dimethyl Hypoxanthine* is decomposed when heated with hydrochloric acid into methylamine and sarcosine (p. 387) (B. **26,** 1914). The position of the oxygen atom is determined by the transformation of adenine into hypoxanthine by nitrous acid; also by its formation from the decomposition of the synthetic

2-thio-6-oxypurine 

$$HSC\left\langle\begin{array}{c} NH.CO.C.NH \\ \qquad\quad \| \\ N\text{———}C\text{—}N \end{array}\right\rangle CH.$$

Adenine, 6-*Aminopurine*, $C_5N_5H_5$ (constitutional formula, p. 587). m.p. 360–368° with decomposition (B. **30,** 2242), is a polymer of hydrocyanic acid. It is obtained from the pancreas of cattle, and occurs in extract of tea. It crystallizes with 3 molecules of water in mother-of-pearl crystals, which lose water at 54° and turn white. Nitrous acid converts it into hypoxanthine; hydrochloric acid at 180–220° into glycocoll, ammonia, formic acid and carbon dioxide (*Kossel*, B. **23,** 225; **26,** 1914). The position of the amino-group is fixed by the connection of adenine with 6-*amino*-2,8-*dioxypurine* through dichloradenine; fuming hydrochloric acid converts dichloradenine into 6-amino-2,8-dioxypurine, which on decomposition does not yield guanidine, showing that the amino-group must be in the 6-position and not in the 2 or 8.

Synthesis of adenine from 2-thio-4,5,6-triaminopyrimidine (p. 587). The analogous formation of purine derivatives still richer in nitrogen, such as 2-*amino-adenine*, $C_5N_4H_2(NH_2)_2$, from malonic nitrile, guanidine, etc., see B. **37,** 4544.

Heteroxanthine, Theobromine, Paraxanthine, Theophylline, Theïne (or **Caffeïne**), are all methyl derivatives of xanthine.

Heteroxanthine, 7-*Methyl Xanthine*, $C_5H_3N_4O[7](CH_3)$, occurs in small quantities in urine, and is formed from theobromine by the loss of methyl. By methylation it is converted into caffeïne; hydrochloric acid decompose it into sarcosine (B. **32,** 469). Electrolytic reduction produces *desoxyheteroxanthine*, which on oxidation forms 7-*methyl*-2-*oxypurine* (comp. p. 588). The isomeric 3-*methyl xanthine* is prepared from 3-methyl uric acid (p. 583), and also from cyanacetyl methyl urea, $CN.CH_2CO.NHCONH.CH_3$, as shown in diagram 3 of the uric acid synthesis (p. 586).

Theobromine, 3,7-*Dimethyl Xanthine*, $C_5H_2N_4O_2[3,7](CH_3)$, occurs in the cocoa beans of *Theobroma cacao;* it is artificially prepared by methylating xanthine (p. 588) or 3-methyl xanthine (B. **33,** 3050).

Theobromine forms a bitter-tasting crystalline powder, slightly soluble in hot water and alcohol, but is fairly easily soluble in ammonia. It sublimes unchanged when carefully heated at 290°. Its reaction is neutral, but it forms crystalline salts with acids, which are decomposed by excess of water. Its silver salt, $C_7H_7AgN_4O_2$, and iodomethane produces *caffeïne*. Electrolytic reduction produces *desoxytheobromine*, which on oxidation yields 3,7-dimethyl-2-oxypurine (comp. p. 588). Theobromine on oxidation is converted into oxy-3,7-dimethyl uric acid (B. **31,** 1450); potassium chlorate and hydrochloric acid decompose it into monoethyl alloxan and monomethyl urea. The action of dry chlorine on theobromine (B. **30,** 2604).

Theobromic Acid, $C_7H_8N_4O_5$.

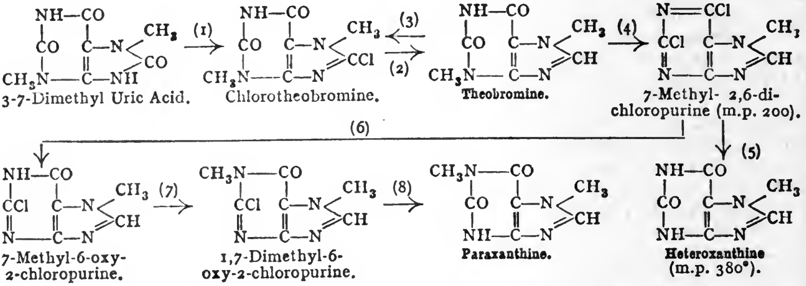
Pseudotheobromine is formed from the silver xanthine compound and iodomethane (C. 1898, I. 1132).

Paraxanthine, 1,7-*Dimethyl Xanthine*, $C_5H_2N_4O_2[1,7](CH_3)_2$, m.p. 289°, occurs in urine (B. **18,** 3406). It is prepared from theobromine by the removal of methyl and its replacement in another position (see below for synthesis). It is obtained from 1,7-dimethyl uric acid, as theobromine is from the 3,7-compound (B. **32,** 471). Methylation produces caffeïne (B. **30,** 554).

SYNTHESIS OF HETEROXANTHINE, THEOBROMINE, AND PARAXANTHINE

7-Methyl pseudouric acid yields 7-methyl uric acid, which by methylation gives 3,7 -dimethyl uric acid. $POCl_3$ converts (1) 3,7-dimethyl uric acid into chlorotheobromine, which is reduced (2) by hydriodic acid to theobromine, and which is formed from theobromine (3) by iodine chloride.

When theobromine is heated with $POCl_3$ and PCl_5 (4) it loses a methyl group and forms 7-methyl 2,6-dichloropurine which with hot fuming hydrochloric acid gives *heteroxanthine*. If 7-methyl-2,6-dichloropurine is boiled with dilute aqueous sodium hydroxide, it is converted into 7-methyl-6-oxy-2-chloropurine. If the potassium salt of this body is methylated (7), there is formed 1, 7-dimethyl-6-oxy-2-chloropurine from which hot fuming hydrochloric acid produces (8) paraxanthine (B. **32**, 469).



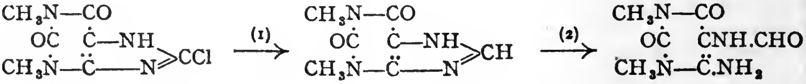
3-7-Dimethyl Uric Acid. Chlorotheobromine. **Theobromine.** 7-Methyl- 2,6-dichloropurine (m.p. 200).

7-Methyl-6-oxy-2-chloropurine. 1,7-Dimethyl-6-oxy-2-chloropurine. **Paraxanthine.** **Heteroxanthine** (m.p. 380°).

The constitution of 7-methyl-6-oxy-2-chloropurine is so assigned, because its reaction product with ammonia gives guanidine when oxidized with chlorine, so that it must be 7-methyl-6-oxy-2-aminopurine. This establishes the constitution of heteroxanthine.

The product of methylating 7-methyl-6-oxy-2-chloropurine can only have the second methyl group in the 1-position, whereby the 1,7-position of the methyl group in paraxanthine is determined.

Theophylline, 1,3-*Dimethyl Xanthine*, m.p. 264°, was discovered in 1888 by *Kossel* in tea extract. By the action of methyl iodide on silver theophylline he obtained caffeïne (B. **21**, 2164). Theophylline has been synthetically prepared from 1,3- or γ-dimethyl uric acid by its conversion with PCl_5 into *chlorotheophylline*, m.p. 300° with decomposition; hydriodic acid reduces it to theophylline (*E. Fischer*, B. **30**, 553). A shorter synthesis is from cyanacetyl dimethyl urea, $CN.CH_2.CON(CH_3)CONH.CH_3$, in which, following diagram 3 of the uric acid synthesis (p. 586), this body is converted into: 1,3-dimethyl 4,5-diaminouracil, of which the formyl-compound (2) is converted into theophylline when warmed with alkalis (B. **33**, 3052; C. 1903, I. 370).



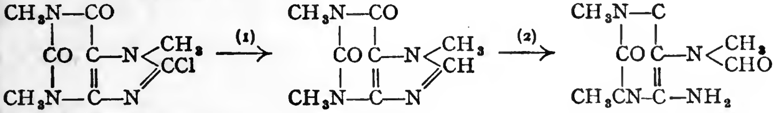
Caffeïne, Coffeïne, Theïne, 1,3,7-*Trimethyl Xanthine*, $C_8H_{10}N_4O_2$, m.p. 239°, occurs in the leaves and beans of the coffee tree (0·5 per cent.), in tea (2–4 per cent.), in Paraguay tea (from *Ilex paraguayensis*), in guarana (about 5 per cent.), the roasted pulp of the fruit of *Paullinia sorbilis*, and in the kola nuts (3 per cent.). It is also found in minute quantities in cocoa. It is used in medicine as a nerve stimulant.

Caffeïne crystallizes with one molecule of water. It has a feeble bitter taste, and forms salts with the strong mineral acids, which are readily decomposed by water. On evaporating a solution of chlorine water containing traces of caffeïne there remains a reddish-brown spot, which acquires a beautiful violet-red colour when dissolved in aqueous ammonia. See also sarcosine (p. 387). Electrolytic reduction converts caffeïne into *Desoxycaffeïne* (comp. p. 588).

Sodium hydroxide converts theïne into *caffeïdine carboxylic acid*, $C_7H_{11}N_4O.CO_2H$, which readily decomposes into CO_2 and *caffeïdine*, $C_7H_{12}N_4O$ (B. **16**, 2309). For other caffeïne derivatives (*apocaffeïne, caffuric acid, caffolin*) see A. **215**, 261, and **228**, 141.

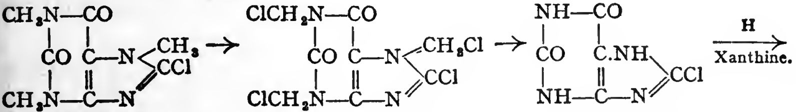
Chlorine water breaks caffeïne up into dimethyl alloxan and methyl urea (p. 579). Chlorine and bromine convert caffeïne into *Chlorocaffeïne*, m.p. 180°, and *Bromocaffeïne*, m.p. 206°. Zinc dust reduces both of them to caffeïne; ammonia and bromocaffeïne produce *aminocaffeïne*, which behaves like an aromatic amine (Vol. II.) in so far that it yields *diazocaffeïne* with nitrous acid, which can be coupled to form *caffeïne diazo-* bodies (C. 1900, I. 407). Sodium methoxide converts chlorocaffeïne into *methoxycaffeine*, m.p. 174°, which when heated to 200° is converted into tetramethyl uric acid (B. **35**, 1991). The latter is decomposed by hydrochloric acid into chloromethane and *hydroxycaffeïne*, m.p. 345°. This is identical with 1,3,7-*trimethyl uric acid*. PCl_5 converts hydroxycaffeïne into chlorocaffeïne. Proceeding from dimethyl alloxan, 1,3,7-trimethyl uric acid may be synthetically made (p. 586), and from this caffeïne through chlorocaffeïne. Furthermore, the lower homologues of caffeïne—theobromine and theophylline—can be synthesized, and by introducing methyl into them caffeïne will result. This, then, is an additional synthesis of caffeïne (*E. Fischer*, B. **30**, 549).

Finally, caffeïne can be produced from the already synthesized 1,3-dimethyl-4,5-diaminouracil (see above, theophylline) by preparing the formyl compound, methylating it (below) and heating the product (B. **33**, 3054):



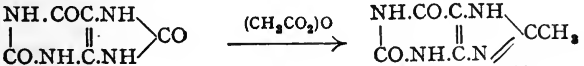
Chlorocaffeïne, from 1,3,7-Trimethyl-uric Acid. Caffeïne Formyl Methyl 4,5-diamino-1,3-dimethyl Uracil.

Just as caffeïne can be built up by exhaustive methylation of xanthine and the lower methyl xanthines, so these bodies are obtained by the breaking down of caffeïne. Chlorocaffeïne (see above) treated with chlorine and $POCl_3$ at low temperatures gives a product in which the 7-methyl group is chlorinated, whilst at higher temperatures the 3-methyl group is attacked; if excess of chlorine be employed a *tetrachlorocaffeïne* results, in which all three methyl groups are chlorinated. When boiled with water, these methyl groups are lost in the form of formaldehyde, and by reduction hydrogen may be exchanged for the chlorine in the α-position (B. **39**, 423):



8-Chlorocaffeïne. Tetrachlorocaffeïne. 8-Chloroxanthine.

8-*Alkyl Xanthines* are obtained from the corresponding uric acids by heating them with carboxylic anhydrides (C. 1901, II. 71).



Uric Acid. 8-Methyl Xanthine.

The methyl group in these substances is easily chlorinated: 8-*trichloromethyl xanthine* can be converted into xanthine 8-carboxylic acids, as can 3-*methyl xanthine* 8-*carboxylic acid*, $C_5H_2N_4O_2[3]CH_3[8]CO_2H$, *caffeïne* 8-*carboxylic acid*, $C_5H_4O_2[1,3,7](CH_3)_3[8]CO_2H$, *theobromine* 8-*carboxylic acid*, $C_5HN_4O_2[3,7](CH_3)_2[8]CO_2H$. The acids lose CO_2 when boiled with water (C. 1904, II. 625).

Carnine, $C_7H_8N_4O+H_2O$, has been found in meat extracts. It is a powder, fairly soluble in hot water, which forms a crystalline compound with hydrochloric acid. Bromine water or nitric acid produces sarcine.

18. TRICARBOXYLIC ACIDS

A. SATURATED TRICARBOXYLIC ACIDS

(*a*) **Tricarboxylic Acids with Two or Three Carboxyls attached to the Same Carbon Atom.**

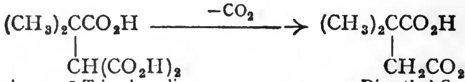
Formation.—(1 *a*) By the action of the halogen fatty-acid esters on the sodium compounds of malonic esters, $CHNa(CO_2R')_2$ and alkyl malonic esters, $R:CNa(CO_2R')_2$—*e.g.* chlorocarbonic ester, chloracetic ester, *a*-bromopropionic ester, *a*-bromobutyric ester, *a*-bromisobutyric ester. (1 *b*) The tricarboxylic esters, resulting in this way from sodium malonic ester, still contain a hydrogen of the CH_2-group of malonic ester, which can be acted on anew with sodium and alkyl iodides. They then yield the same esters which are obtained by starting with the monoalkyl malonic esters.

(2) By the addition of sodium malonic esters to unsaturated carboxylic esters, *e.g.* crotonic ester (B. **24**, 2888; C. 1897, I. 28).

(3) Also, by the gradual saponification of tetracarboxylic esters, containing two carboxyl groups attached to the same carbon atom, which split off carbon dioxide and yield tricarboxylic esters (B. **16**, 333; **23**, 633; A. **214**, 58).

(4) By heating the best adapted ketone-tricarboxylic esters (B. **27**, 797), when a loss of CO occurs.

Like malonic acid, these tricarboxylic acids readily break down with the elimination of CO_2, yielding succinic acids, *e.g.*:



$$\begin{matrix}(CH_3)_2CCO_2H \\ | \\ CH(CO_2H)_2\end{matrix} \xrightarrow{-CO_2} \begin{matrix}(CH_3)_2CCO_2H \\ | \\ CH_2CO_2H\end{matrix}$$

Isobutane *aaβ*-Tricarboxylic Acid. unsym.-Dimethyl Succinic Acid.

For the saponification of tricarboxylic esters consult B. **29**, 1867.

Formyl Tricarboxylic Ester, Methane Tricarboxylic Ester Malonic Carboxylic Ester, $CH(CO_2C_2H_5)_3$, m.p. 29°, b.p. 253°, is obtained from sodium malonic ester, $CHNa(CO_2C_2H_5)_2$, and ethyl chlorocarbonate (B. **21**, R. 531).

Methane Tricarboxylic Diphenylamidine Diethyl Ester, $(C_2H_5OOC)_2CH.C\begin{smallmatrix}\diagup NC_6H_5\\ \diagdown NHC_6H_5\end{smallmatrix}$, m.p. 167°, is formed by the combination of sodium malonic ester and carbodiphenylimide, $C(NC_6H_5)_2$, (Vol. II.) (B. **32**, 3176).

Cyanomalonic Ester, $CH(CN)(CO_2R)_2$, results from the action of cyanogen chloride on sodium malonic ester. It volatilizes without decomposition under greatly reduced pressure. It has a very acid reaction, and decomposes the alkali carbonates, forming salts, like $CNa(CN)(CO_2R)_2$ (B. **22**, R. 567; C. 1901, I. 675).

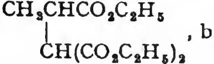
Cyanoform, $CH(CN)_3+CH_3OH$ (?), m.p. 214°, with decomposition. Sodium cyanoform is produced when cyanogen chloride acts on malonitrile and sodium ethoxide (B. **29**, 1171).

Ethenyl Tricarboxylic Ester, Ethane Tricarboxylic Ester, Succinic Carboxylic Ester, $C_2H_5OOC.CH_2.CH(COOC_2H_5)_2$, is obtained from sodium ethyl, b.p. 278°, malonate and the ester of chloracetic acid. Chlorine converts it into *Chlorethane Tricarboxylic Ester*, $C_2H_2Cl(CO_2C_2H_5)_3$, b.p. 290°. When heated with hydrochloric acid, it yields carbon dioxide, hydrochloric acid, alcohol, and fumaric acid; when hydrolyzed with alkalis, carbon dioxide and malic acid are the products (A. **214**, 44).

Methyl a-Cyanosuccinic Ester, $(CO_2CH_3)CH_2CH(CN)CO_2CH_3$, is obtained from methyl cyanacetic ester and chloracetic ester (B. **24**, R. 557).

αβ-Dicyanopropionic Ester, $NC.CH_2CH(CN)CO_2C_2H_5$, b.p.$_{20}$ 169°, is prepared from formaldehyde cyanhydrin and sodium cyanacetic ester, $CNCH_2OH+NaCH(CN)CO_2R=CN.CH_2CNa(CN)CO_2R+H_2O$. The cyanhydrins of homologous aldehydes and ketones condense similarly: *αβ-Dicyanisovaleric Ester*, $NC.C(CH_3)_2CH(CN)CO_2C_2H_5$, b.p.$_{22}$ 150°; *αβ-Dicyanopelargonic Ester*, $C_6H_{11}CH(CN)CH(CN)CO_2C_2H_5$, b.p.$_{20}$ 192° (C. 1906, II. 1562), etc.

Propane ααβ-Tricarboxylic Ester,

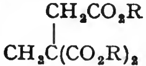


$$\begin{array}{l}CH_3CHCO_2C_2H_5\\ |\\ CH(CO_2C_2H_5)_2\end{array}$$

, b.p. 270°.

The free acid (isomeric with tricarballylic acid), m.p. 146°, breaks down into carbon dioxide and pyrotartaric acid.

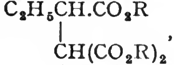
Propane αββ-Tricarboxylic Ester,



$$\begin{array}{l}CH_2CO_2R\\ |\\ CH_3C(CO_2R)_2\end{array}$$

, b.p. 273°.

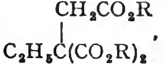
n.-*Butane ααβ-Tricarboxylic Ester*,



$$\begin{array}{l}C_2H_5CH.CO_2R\\ |\\ CH(CO_2R)_2\end{array}$$

, b.p. 278°.

n.-*Butane αββ-Tricarboxylic Ester*,



$$\begin{array}{l}CH_2CO_2R\\ |\\ C_2H_5C(CO_2R)_2\end{array}$$

, b.p. 281°.

n.-*Butane ααδ-Tricarboxylic Ester*, $(CO_2R)CH_2CH_2CH_2CH(CO_2R)_2$, b.p.$_{40}$ 203° (C. 1897, II. 542).

Isobutane ααβ-Tricarboxylic Ester, $(CO_2R)C(CH_3)_2.CH(CO_2R)_2$, b.p. 277°. (Comp. B. **23**, 648).

unsym.-*Dimethyl Cyanosuccinic Ester*, $CO_2R.CH(CN).C(CH_3)_2.CO_2R$, b.p. 186°, is formed from sodium cyanacetic ester and bromoisobutyric ester (B. **27**, R. 506; C. 1899, I. 593, 873).

α-Cyanoglutaric Ester (B. **27**, R. 506).

α-Alkyl α-Carboxyl Glutaric Ester (A. **292**, 209; C. 1897, I. 28).

α-Cyano-β-isopropyl-glutaric Ester, b.p.$_{30}$ 195° (C. 1899, I. 1157).

β-Methyl Propane ααγ-Tricarboxylic Acid, *β-Methyl Glutaric α-Carboxylic Ester*, $(CO_2R)_2CHCH(CH_3)CH_2CO_2R$, b.p.$_{11}$ 165° is formed from sodium malonic ester and crotonic ester, and gives, somewhat remarkably, a *sodium salt* of the constitution $(CO_2R)_2CH.CH(CH_3)CHNaCO_2R$, which, with iodomethane yields *βγ-Dimethyl Propane ααγ-Tricarboxylic Ester*, $(CO_2R)_2CHCH(CH_3)CH(CH_3)CO_2R$, b.p.$_{10}$ 167°. This substance is isomeric with *αβ-Dimethyl Propane ααγ-Tricarboxylic Acid*, $(CO_2R)_2C(CH_3)CH(CH_3)CH_2CO_2R$, b.p.$_{10}$ 161°, prepared from sodium methyl malonic ester and crotonic ester. This substance yields a *sodium salt* which, with iodomethane gives *αβγ-trimethyl propane ααγ-tricarboxylic acid* (B. **33**, 3731).

ββ-Dimethyl α-Carboxyl Glutaric Ester, see ββ-Dimethyl Glutaric Acid (p. 504).

ββ-Dimethyl α-Cyanoglutaric Ester (C. 1899, I. 252, 532).

(*b*) **Tricarboxylic Acids with the Carboxyl Groups attached to Three Carbon Atoms.** There are many members of this class which are obtained through loss of CO_2 from tetra- and penta-carboxylic acids, which possess one or two pairs of CO_2H-groups attached to the same carbon atom (B. **24**, 307, 2889; **25**, R. 746; C. 1902, I. 110).

Tricarballylic Acid, $CH_2(CO_2H).CH(CO_2H).CH_2(CO_2H,)$, m.p. 162–164°, occurs in unripe beetroot, and is found in the deposit in the vacuum pans during the manufacture of beet sugar. It is prepared (1) by reduction of aconitic acid (p. 594) (A. **314**, 15; C. 1903, II. 187), and of citric acid (p. 610); (2) synthetically from allyl ribromide, $CH_2Br.CHBr.CH_2Br$ and KNC, and decomposition of he tricyanide with aqueous potassium hydroxide: also from a whole eries of synthetically prepared bodies by cleavage reactions; (3) from diallyl acetic acid (p. 306) by oxidation; (4) from α-acetyl tricarballylic acid ester (p. 612) by hydrolysis (B. **23**, 3756); (5) from propane $\alpha\alpha\beta\gamma$- and -$\alpha\beta\beta\gamma$-tetracarboxylic ester; (6) from cyanotricarballylic ester, the product of combination of sodium cyanosuccinic ester and bromacetic ester (C. 1902, I. 409); (7) from propane pentacarboxylic ester (p. 622), with loss of CO_2 (B. **25**, R. 746). It forms prisms which are easily soluble in water.

The *silver salt*, $C_6H_5O_6Ag_3$; *calcium salt*, $(C_6H_5O_6)_2Ca_3+4H_2O$, dissolves with difficulty (C. 1902, I. 409); *trimethyl ester*, $C_6H_5O_6(CH_3)_3$. b.p.$_{13}$ 150°; *chloride*, $C_3H_5(COCl)_3$, b.p.$_{14}$ 140° (B. **22**, 2921); *anhydride acid*, $C_6H_6O_5$, m.p. 131° (B. **24**, 2890); *triamide*, $C_3H_5(CONH_2)_3$, m.p. 206°; *amidimide*, $C_6H_8O_3N_2$, m.p. 173° (B. **24**, 600). *Trihydrazide* and *Triazide*, $C_3H_5(CON_3)_3$ (J. pr. Ch. [2] **62**, 235).

Homologous Tricarballylic Acids:

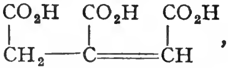
α-Methyl-, two modifications, m.ps. 180° and 134° (comp. M. **23**, 283); *β-Methyl-*, m.p. 164°; *α-Ethyl-*, m.p. 147°; *α-n.-propyl*, m.p. 151°; *α-isopropyl*, m.p. 161° (B. **24**, 288); *αα₁-dimethyl-*, three modifications (B. **29**, 616); *αα-dimethyl-*, three modifications, m.ps. 143°, 174°, and 206° (C. 1899, I. 826; 1900, II. 316; 1902, I. 409). These acids are prepared from the corresponding cyanotricarballylic acids (the condensation products of sodium cyanosuccinic esters and α-bromo-fatty acid esters), or from sodium cyanoacetic esters and alkyl bromosuccinic esters. Trimethyl bromosuccinic ester, however, after reaction with sodium cyanacetic ester, hydrolysis and cleavage of the product of condensation, does not yield the expected trimethyl tricarballylic acid, but *αα-dimethyl butane αβα₁-tricarboxylic acid* $(CH_3)_2C(COOH)CH(COOH)CH_2CH_2COOH$ (C. 1902, I. 409).

ααβ-**Trimethyl Tricarballylic Acid, Camphoronic Acid,** $(CH_3)_2C(CO_2H)C(CH_3)$-$(CO_2H).CH_2CO_2H$. m.p. 135°, is formed when camphor is oxidized. It is of fundamental importance in the determination of the constitution of camphor (Vol. II.). *αβδ Butane Tricarboxylic Acid*, m.p. 119° (C. 1902, II. 732).

αγδ-Pentane Tricarboxylic Acid, Hæmotricarboxylic Acid, two modifications, m.p. 141° and 175°, is formed by the acid reduction of hæmatinic acid (p. 595) (A. **345**, 2).

αγε-Pentane Tricarboxylic Acid, m.p. 107° (B. **24**, 284). *Butane βδ-Dicarboxylic γ-Acetic Acid*, $CH_3CH(COOH)CH(CH_2COOH)_2$ (M. **21**, 879). *Methine α-Tripropionic Ester*, $CH[CH(CH_3)CO_2R]_3$, m.p. 201°, is prepared from orthoformic ester, α-bromopropionic ester and zinc (C. 1906, I. 338).

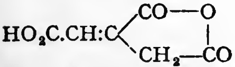
B. OLEFINE TRICARBOXYLIC ACIDS

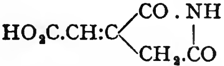
Aconitic Acid,  $\underset{CH_2}{\overset{CO_2H}{|}}\!-\!\!-\underset{C}{\overset{CO_2H}{|}}\!=\!\!=\underset{CH}{\overset{CO_2H}{|}}$, m.p. 191°, with decomposition into CO_2 and itaconic anhydride (p. 516). It is isomeric with trimethylene tricarboxylic acid (*q.v.*), and occurs in different plants; for example, in *Aconitum napellus*, in *Equisetum fluviatile*, in sugar cane, and in beet roots. It is obtained by heating citric acid alone or with concentrated hydrochloric or sulphuric acid (B. **20**, R. 254; A. **314**, 15).

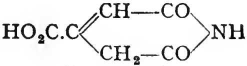
Aconitic acid has been synthetically prepared by the decomposition of oxalocitric lactone ester (*q.v.*) with alkali; by the decomposition of the addition product of sodium malonic ester and acetylene dicarboxylic ester (J. pr. Ch. [2] **49**, 20); also from cyanaconitic acid, the product of reaction of cyanacetic ester, oxaloacetic ester and sodium ethoxide (C. 1906, II. 20). It is readily soluble in water, and is reduced by nascent hydrogen to tricarballylic acid.

The *calcium salt*, $(C_6H_3O_6)_2Ca_3+6H_2O$, dissolves with difficulty; *trimethyl ester*, $C_6H_3O_6(CH_3)_3$, b.p.$_{14}$ 161°, results from the distillation of acetyl citric trimethyl ester (B. **18**, 1954), and from aconitic acid, methyl alcohol, and hydrochloric acid (B. **21**, 669).

unsym.-*Aconitic Anhydride Acid*, $C_6H_4O_5$ (constitutional formula, see below), m.p. 76°, is formed when aconitic acid is heated in vacuo to 140°, and when it is treated with acetyl chloride. When distilled in vacuo it decomposes into CO_2 and itaconic anhydride (B. **37**, 3967). unsym.-*Aconitimide Acid*, $C_6H_4O_4(NH)$ (constitutional formula, see below), m.p. 191°, is formed from acyl citrimide ester and alkalis (p. 611); also from β-anilinotricarballylimide esters and dilute hydrochloric acid (B. **23**, 3185, 3193). But the aconitic esters and ammonia yield the amide of sym.-*aconitimide acid, citrazinic acid* (formula, see below) (Vol. II.), which results also from the amide of citric acid and mineral acids (B. **22**, 1078, 3054; **23**, 831; **27**, 3456):


unsym.-Aconitic Anhydride Acid.


unsym.-Aconitimide Acid.


Citrazinic Acid.

α-(or γ)-*Methyl Aconitic Acid*, $HO_2C.C(CH_3):C(CO_2H)CH_2CO_2H$ or $HO_2C.CH.-CH_2C.(CO_2H):CHCO_2H$, m.p. 159°, is prepared from methyl cyanaconitic ester (p. 615). It reacts with acetyl chloride to form an *anhydride acid*, m.p. 51°, which when heated to 159° decomposes into β-methyl itaconic anhydride and CO_2. *αγ-Dimethyl Aconitic Acid*, m.p. 164°; the *anhydride-acid*, m.p. 74°, is formed from cyano-αγ-dimethyl-aconitic ester (C. 1906, II. 21).

Isoaconitic Ethyl Ester, $(C_2H_5OOC)_2CHCH:CHCOOC_2H_5$, is formed when dicarboxylic glutaconic ester is incompletely hydrolyzed. It is converted by piperidine into a bimolecular polymer which yields a *bimeric* glutaconic acid, m.p. 207° (p. 520) on hydrolysis with hydrochloric acid (B. **34**, 677).

Aceconitic Acid and *Citracetic Acid*, $C_6H_6O_6$, are two acids of unknown constitution, isomeric with aconitic acid. They are obtained by the action of sodium on bromoacetic ester (A. **135**, 306; comp. B. **27**, 3457).

αγδ-Butene Tricarboxylic Acid, $HOOC.CH_2CH(CO_2H)CH:CHCO_2H$, m.p. 148° (C. 1902, II. 732).

Δ^3-*Pentene αγδ-Tricarboxylic Acid*, $HO_2C.CH_2CH_2C(CO_2H):CH.CO_2H$, is unknown in the free state. Its *anhydride-* and *imide-acid* are identical with the *hæmatic acids*, obtained from hæmatin (*q.v.*) by the ordinary action of chromic acid. The acids decompose on dry distillation into CO_2 and methyl ethyl maleïc anhydride and imide, respectively (p. 519) (A. **345**, 1).

VI. TETRAHYDRIC ALCOHOLS AND THEIR OXIDATION PRODUCTS

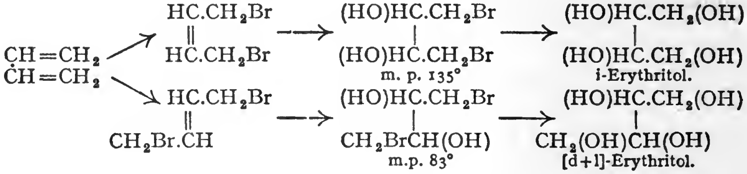
Theoretically, there are 15 classes of tetrahydric alcohols, a figure which is obtained by the combination of the individuals—CH_2OH, $=CHOH$, $\equiv COH$, according to the formula, $\frac{m(m+1)(m+2)(m+3)}{1\,.\,2\,.\,3\,.\,4}$, etc., where $m=3$. The number of possible classes of oxidation products can be calculated by combining the six individuals—CH_2OH, $=CHOH$, $\equiv COH$, —CHO, $=CO$, —CO_2H, substituting $m=6$ in the above equation and subtracting the number 15 of the tetrahydric alcohols. Thus, it is found that there are 111 classes (126−15) of oxydation products, a number which is diminished when the 10 different classes of trihydroxy-aldehydes, the 10 classes of trihydroxy-ketones, and the 10 classes of trihydroxy-carboxylic acids are reckoned as 3 main classes. The more so when the 6 classes each of the dihydroxy-dialdehydes, dihydroxy-diketones, dihydroxy-aldehyde-ketones, dihydroxy-aldehyde-carboxylic acids, dihydroxy-keto-carboxylic acids and di-hydroxy-dicarboxylic, acids are considered as constituting 6 main classes. Further, the 3 classes each of the monohydroxy-trialdehydes, monohydroxy-dialdehyde diketones, monohydroxy-aldehyde-diketones, monohydroxy-triketones, monohydroxy-dialdehyde-monocarboxylic acids, monohydroxy-monoaldehyde dicarboxylic acids, monohydroxy-aldehyde-ketone-carboxylic acids, monohydroxy-diketone-carboxylic acids, monohydroxy-mono-ketone-dicarboxylic acids, and monohydroxy-tricarboxylic acids, can all be reduced to 10 main classes. There remains still 15 classes of oxidation products, composed of the fourfold combination of the three individuals,—CHO, =CO, —CO_2H. Thus, the total number of main classes of the oxidation of the 15 classes of tetrahydroxy-alcohols is $3+6+10+15=34$ classes.

These considerations give a clear indication of how little the field of the tetrahydroxy alcohols and their oxidation products has been exhausted, since only 15 classes are as yet known.

1. TETRAHYDRIC ALCOHOLS

Ordinary erythritol is best known of the tetrahydric alcohols corresponding with the four tartaric acids (p. 600). By an intramolecular compensation it, like mesotartaric acid, becomes optically inactive, and is therefore called i-erythritol. This alcohol and [d+l] erythritol were synthetically prepared by *Griner* in 1893 from divinyl.

Divinyl, or butadiëne (p. 88), forms an unstable dibromide, which becomes rearranged at 100° into two different but stable dibromides. When these are oxidized by potassium permanganate, the one passes into the dibromhydrin (m.p. 135°) of ordinary or i-erythritol, whilst the other becomes the dibromhydrin (m.p. 83°) of [d+l] erythritol. Potassium hydroxide converts these two dibromhydrins into two butadiëne oxides, which, with water, yield the erythritols corresponding with i- and [d+l] erythritol (B. **26**, R. 932 ; A. **308**, 333):



i-Erythritol, *Erythroglucin, Phycitol*, $CH_2(OH).CH(OH.)CH(OH).CH_2.OH$, m.p. 126°, b.p. 330°, occurs free in the alga *Protococcus vulgaris*. It exists as erythrin (orsellinate of erythritol) in many lichens and some algæ, especially in *Roccella Montagnei*, and is obtained from these by hydrolysis with sodium hydroxide or calcium hydroxide.

$$\underset{\text{Erythrin.}}{C_4H_6\begin{cases}(OH)_2\\(O.C_8H_7O_3)_2\end{cases}}+2H_2O=\underset{\text{Erythritol.}}{C_4H_6(OH)_4}+\underset{\text{Orsellinic Acid.}}{2C_8H_8O_4}.$$

Also, i-erythritol is formed by the reduction of i-erythrose (B. **32**, 3677).

Like all polyhydric alcohols erythritol possesses a sweet taste.

By carefully oxidizing erythritol with dilute nitric acid *erythrose* results. More intense oxidation produces erythritic acid and mesotartaric acid (p. 604).

i-*Nitro-erythritol*, $C_4H_6(ONO)_{24}$, m.p. 61°, explodes violently when struck. i-*Tetra-acetyl Erythritol*, $C_4H_6(OCOCH_{34})$, m.p. 85°. i-*Erythritol Dichlorhydrin*, $C_4H_8(OH)_2Cl_2$, m.p. 125°, is formed from erythritol by the action of concentrated hydrochloric acid. i-*Erythritol Ether*,  $\overbrace{CH_2.CH}^{O}.\overbrace{CH.CH_2}^{O}$, b.p. 138°, $D_{18}=1{\cdot}113$, is formed when potassium hydroxide acts on the dichlorhydrin. It is a liquid with a penetrating odour, and behaves like ethylene oxide (p. 317). It combines slowly with water, yielding erythritol, with 2HCl to the dichlorhydrin, and with 2HNC to the nitrile of dihydroxyadipic acid (B. **17**, 1091). Erythritol, in the presence of hydrochloric acid, combines with formaldehyde, benzaldehyde, and acetone, yielding:

i-*Erythritol Diformal*, $C_4H_6O_4(CH_2)_2$, m.p. 96° (A. **289**, 27);

i-*Erythritol Dibenzal*, m.p. 97°; and

i-*Erythritol Diacetone*, $C_4H_6O_4(C_3H_6)_2$, m.p. 56°, b.p.$_{29}$ 105° (B. **28**, 2531).

d-Erythritol, m.p. 88, $[\alpha]_D = -4{\cdot}4°$, is obtained by the reduction of erythrulose (C. 1900, II. 31). **l-Erythritol**, $[\alpha]_D = +4{\cdot}3°$, is similarly obtained from l-threose (C. 1901, II. 179).

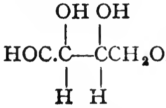
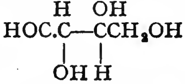
[d+l]-Erythritol, m.p. 72°, is obtained by the combination of the d- and l-compounds. It is identical with the substance obtained from divinyl (p. 596).

[d+l]-*Erythritol Ether* (B. **26**, R. 932). *Tetraacetyl*-[d+l]-*Erythritol*, m.p. 53°.

Nitro-tert.-Butyl Glycerol, $NO_2C(CH_2OH)_3$, m.p. 158°, is formed from nitromethane, formaldehyde, and potassium hydrogen carbonate (B. **28**, R. 774). Reduction converts it into *hydroxylamino-tert.-butyl-glycerol*, $HOHN.C(CH_2OH)_3$, m.p. 140° (B. **30**, 3161). See also Dioxyacetone (p. 534).

Penta-erythritol, $C(CH_2OH)_4$, m.p. 250–255°, has been prepared by condensing formaldehyde and acetaldehyde with lime (C. 1901, II. 1114). See also vinyl-trimethylene (Vol. II.). *Tetraacetyl Penta-erythritol*, $C(CH_2OCOCH_3)_4$, m.p. 84° (A. **276**, 58). *Penta-erythritol Dibenzal*, m.p. 160° (A. **289**, 21). *Tetra-ethyl Ether*, $C(CH_2OC_2H_5)_4$, b.p. 220° (C. 1897, II. 694). Two **Hexyl Erythritols** have been prepared by oxidizing diallyl, $CH_2{=}CH.CH_2{-}CH_2{-}CH{=}CH_2$ (p. 90). Oxidation of hexadiëne dibromide, $CH_3CHBrCH:CHCHBrCH_3$, produces a *dibromo-di-hydroxyhexane* which, when warmed with aqueous sodium hydroxide yields *Hexylene Dioxide*,  $\overline{O.CH(CH_3)CH}.\overline{CH.CH(CH_3).O}$, b.p. 177° (B. **35**, 1341).

2. **TRIHYDROXYALDEHYDES** and 3. **TRIHYDROXYKETONES**: **Erythritose**, *Tetrose*, is probably a mixture of a trihydroxyaldehyde and a trihydroxyketone (comp. *Glycerose*, p. 534; B, **35**, 2627). It is produced when erythritol is oxidized with dilute nitric acid. It yields **phenylerythrosazone**, $C_4H_6O_2(N_2HC_6H_5)_2$, m.p. 167° (B. **20**, 1090). This probably is also produced from the condensation product of glycolyl aldehyde (p. 337) (B. **25**, 2553; **35**, 2630).

d-**Erythritose** (*lævo-rotatory*) is formed when d-arabonic acid is oxidized with hydrogen peroxide (B. **32**, 3674). **l-Erythritose**,  $HOC.\overset{OH}{\underset{H}{C}}{-}\overset{OH}{\underset{H}{C}}CH_2OH$ (*dextro-rotatory*) results from the oxidation of l-arabonic acid, or by the decomposition of l-arabinose oxime through the nitrile, by loss of hydrocyanic acid (B. **32**, 3666; **34**, 1365) (comp. also the decomposition of d-dextrose, p. 618). Similarly, by oxidation, or by the hydrocyanic acid reaction, l-xylose yields l-*threose*,  $HOC.\overset{H}{\underset{OH}{C}}{-}\overset{OH}{\underset{H}{C}}CH_2OH$ stereosomeric with erythrose. l-Erythritose and l-threose yield the same osazone (B. **34**, 1370). *Erythrulose* is obtained from erythritol by means of the *Sorbose bacterium*. It yields d-erythritol on reduction, and is probably a ketose. *Methyl Tetrose*, $CH_3[CHOH]_3CHO$, is obtained from rhamnose oxime and acetic anhydride, and also from rhamnonic acid and hydrogen peroxide, *iosazone*, m.p. 173°. *Benzyl Phenylhydrazone*, m.p. 97°, when oxidized with nitric acid, yields d-*tartaric acid*; bromine water produces methyl tetronic acid (B. **29**, 138; **35**, 2360).

4. **HYDROXYTRIKETONES:** 3-*Methyl-heptane*-3-ol-2,5,6-*trione*, *aldol* of *diacetyl*, $CH_3COC(OH)(CH_3).CH_2CO.COCH_3$, b.p.$_{18}$ 128° (p. 349).

5. **TETRAKETONES:** *Tetra-acetyl Ethane*, $(CH_3CO)_2CH{-}CH(COCH_3)_2$, is obtained from sodium acetyl acetone by means of iodine or by electrolysis (p. 350).

Oxalyl Diacetone, $CH_3COCH_2.COCO.CH_2COCH_3$, m.p. 121°, and *Oxalyl Dimethyl Diethyl Ketone*, $C_2H_5COCH_2.COCO.CH_2COC_2H_5$, m.p. 76°, are formed from oxalic ester acetone or methyl ethyl ketone and sodium ethoxide. It consists of yellow crystals, which remain yellow on fusion and form yellow solutions. Oxalyl diacetone give a dipyrazole derivative with phenylhydrazine (A. **278**, 294).

Methenyl Bisacetyl Acetone, $(CH_3CO)_2CH.CH{=}C(COCH_3)_2$, is obtained from ethoxymethylene acetyl acetone (p. 536) by the addition of acetyl acetone.

6. TRIHYDROXY-MONOCARBOXYLIC ACIDS.

Trihydroxybutyric Acid, rac.-*Erythronic Acid, Erythroglucic Acid*, CH_2OH-$[CHOH]_2CO_2H$, is obtained by the oxidation of erythrytol and mannitol (2) (B. **19**, 468). It is a crystalline deliquescent mass. d-*Erythronic Acid* (lævo-rotatory) is formed by the oxidation of d-erythritose with bromine; from d-fructose with HgO; and from the dextrosone (p. 629), with bromine (C. 1902, I. 859; II. 109). d-*Erythronic Lactone*, m.p. 103°. l-*Erythronic Acid* (dextro-rotatory) is prepared from l-erythrose and bromine water.

l-*Erythronic Lactone*, m.p. 104° (B. **34**, 1362).

rac.-*Erythronic Lactone*, m.p. 91°, is obtained from γ-hydroxycrotonic lactone (p. 398), and permanganate. The *γ-ethyl ether* of erythronic acid, $C_2H_5O.CH_2CH$-$OH.CHOH.CO_2H$, m.p. 91°, is similarly obtained from γ-ethoxycrotonic acid (C. 1905, I. 1138; II. 457.

Trihydroxyisobutyric Acid, $(CH_2OH)_2.C(OH)CO_2H$, m.p. 116°, is obtained from glycerose and HNC (B. **22**, 106).

αβγ-Trihydroxyvaleric Acid; *αβ-Dihydroxy-γ-valerolactone*, $CH_3CHCH(OH)$-$CH(OH)COO$, m.p. 100°, is formed by oxidation of α-angelic acid lactone (p. 398) by permanganate (A. **319**, 194). This dehydroxyvalerolactone must be looked on as being the racemic form of the *Methyl Tetronic Acid Lactone*, m.p. 121°, $[\alpha]_D = -47{\cdot}5°$, obtained by oxidation of methyl tetrose (p. 597) by bromine water. *αβγ-Trihydroxyvaleric Acid* is specially characterized by its *phenylhydrazide*, m.p. 169°, and its *brucine salt* (B. **35**, 2365).

1,3,4-*Trihydroxyvaleric Acid*; the 1,4-*oxide* of this acid, the *β-Hydroxytetrahydrofurfurane α-Carboxylic Acid*, $OCH_2.CH(OH)CH_2CHCOOH$, m.p. 110°, is formed from the corresponding malonic acid derivative when it is heated with water (B. **37**, 4544).

The corresponding 1,4-imide—*β′-Hydroxypyrrolidine α-Carboxylic Acid*, *β′-Hydroxyproline*, $HNCH_2CH(OH)CH_2CHCO_2H$, *a*-form, m.p. 26°, with decomposition, *b*-form 250°, with decomposition, is formed from *αδ-bromo-chloro-γ-valerolactone*, $ClCH_2CH.CH_2.CHBr.COO$. The *a*-form yields a slightly soluble copper salt. The last named acid, like the 1,4-oxide (see above) is prepared from the synthetic δ-chlorovalerolactone carboxylic ester (p. 599) by the action of ammonia. It has not yet been determined whether the synthetic hydroxyproline is the racemic form of the *natural Hydroxyproline*, m.p. 270° with decomposition $[\alpha]_D^{20} = -81{\cdot}04°$, which is obtained by the hydrolysis of gelatin. Both compounds possess a sweet taste, are reduced by hydriodic acid and phosphorus to *proline* (p. 542), and are very stable towards hydrolytic agents (B. **41**, 1726).

7. DIHYDROXYKETO-MONOCARBOXYLIC ACIDS.

αγ-Diethoxy-acetoacetic Ester, $C_2H_5O.CH_2CO.CH(OC_2H_5).CO_2C_2H_5$, b.p.$_{14}$ 132°, is prepared from ethoxychloracetoacetic ester (p. 545) and sodium ethoxide (A. **269**, 28).

8. HYDROXYDIKETO-CARBOXYLIC ACIDS.

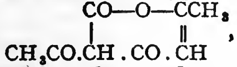
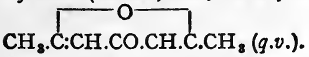
Acetyl Acetone Chloral, $CCl_3.CH(OH)CH_2CO.CH_2COCH_3$, m.p. 78°, is a derivative of heptane-2-ol-4,6-dione-l-acid. It is prepared from chloral and acetyl acetone (C. 1898, II. 704).

9. TRIKETO-MONOCARBOXYLIC ACIDS.

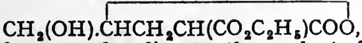
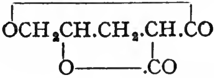
The *β-phenylhydrazone* of *αβγ-Triketo*-n.-*valeric Acid*, m.p. 206°, is prepared from sodium acetone oxalic acid and diazobenzene chloride (A. **278**, 285).

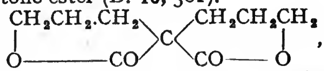
Diacetyl Pyroracemic Acid, $(CH_3CO)_2CHCOCO_2H$, provides a derivative *cyaniminomethyl acetyl acetone* $(CH_3CO)_2CH.C(NH)CN$, which is prepared from acetyl acetone, cyanogen and a little sodium ethoxide. Aqueous sodium hydroxide decomposes it into sodium cyanide and cyanacetyl acetone (p. 547). It combines with a further quantity of acetyl acetone to form dicyano-diacetyl-acetone and similarly with acetoacetic ester and malonic ester (A. **332**, 146).

Derivatives of *pyruvyl pyruvic acid,* $CH_3COCO.CH_2COCOOH$, are formed from pyroracemic ester and aromatic amines, *e.g.*, $CH_3C(NC_6H_5)COCH_2C(NC_6H_5)CO_2C_2H_5$, which is decomposed by sulphuric acid into $CH_3C(NC_6H_5)COCH_2COCO_2C_2H_5$, m.p. 140 (C. 1902, I. 1320). *Homopyruvyl Pyruvic acid, Heptane-3,4,6-trione-7-acid,* provides derivatives such as the *methoxime ester,* $C_2H_5C(NO.CH_3)COCH_2COCO_2R$; *methyl ester,* m.p. 80°; *ethyl ester,* m.p. 41°, which are prepared from the methoxime of acetyl propionyl (pp. 349, 354), oxalic ester, and sodium ethoxide (B. **38**, 1917).

αγ-Diacetyl Acetoacetic Acid, $CH_3COCH_2COCH(COCH_3)CO_2H$. The lactone of the δ-*aci*- or -enol-form of this hypothetical acid, *Dehydracetic Acid, 6-Methyl-3-aceto-pyronone,*  $\begin{array}{l}\qquad\qquad\ \ CO—O—CCH_3\\ \qquad\qquad\ \ |\qquad\qquad\ \|\\ CH_3CO.CH.CO.CH\end{array}$, m.p. 108°, b.p. 269°, is formed by boiling acetoacetic ester under a reflux condenser; from dehydracetocarboxylic acid (A. **273**, 186) by evaporation with aqueous sodium hydroxide; from acetyl chloride and pyridine; and from triacetic acid (p. 548) by heating with acetic anhydride and sulphuric acid (C. 1900, II. 625). It is isomeric with isodehydracetic acid (p. 571). The constitution of dehydracetic acid has been demonstrated by *Feist* (A. **257**, 261; B. **27**, R. 417). Hydriodic acid produces dimethyl pyrone,  $CH_3.\overbrace{C:CH.CO.CH.C}^{O}.CH_3$ (*q.v.*).

10. DIHYDROXY-DICARBOXYLIC ACIDS.

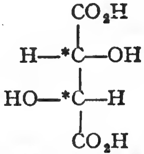
A. Malonic Acid Derivatives, *γδ Dihydroxypropyl Malonic Acid,* $CH_2(OH)CH(OH)CH_2CH(CO_2H)_2$; *lactone ester, δ-hydroxy-γ-valerolactone carboxylic ester,*  $CH_2(OH).\overbrace{CHCH_2CH(CO_2C_2H_5)COO}$, a syrup, is formed from *δ-chloro-γ-valerolactone carboxylic ester,* the product of condensation of epichlorhydrin (p. 532) and malonic ester. The lactone ester and alcoholic ammonia form *γ-δ-Dihydroxypropyl Malonamide,* m.p. 140° (B. **35**, 197); comp. also B. **38**, 1939). Hydrolysis of the chlorovalerolactone ester causes loss of CO_2 and production of chloro-γ-valerolactone, together with the *dilactone*  $\begin{array}{l}\overbrace{OCH_2CH.CH_2.CH.CO}\\ \qquad\ \ |\qquad\qquad\ \ |\\ \qquad\ O\text{———}.CO\end{array}$, m.p. 180°; bromine produces α-bromo-δ-chloro-γ-valero-lactone ester (B. **40**, 301).

Di-ω-hydroxypropyl Malonic Acid Lactone,  $\begin{array}{l}CH_2CH_2.CH_2\diagdown\quad\diagup CH_2CH_2CH_2\\ |\qquad\qquad\quad\ \ >C<\qquad\qquad\quad |\\ O\text{———}CO\diagup\quad\diagdown CO\text{——}O\end{array}$, m.p. 106°, is formed from diallyl malonic acid (p. 522), and hydrobromic acid (A. **216**, 67).

B. SUCCINIC ACID DERIVATIVES.

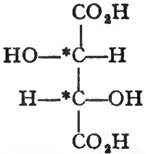
Tartaric Acids or Dihydroxyethylene Succinic Acids.—Tartaric acid is known in four modifications; all possess the same structure and can be converted into one another. They are: (1) *Ordinary* or *Dextro-tartaric acid.* (2) *Lævo-tartaric acid.* These two are distinguished from each other by their equally great but opposite molecular rotatory power. (3) *Racemic Acid, paratartaric acid,* or [d+l]-*tartaric acid.* This is optically inactive, but can be resolved into dextro- and lævo-tartaric acids, from which it can again be reproduced by their union. (4) *Mesotartaric acid, antitartaric acid,* i-*tartaric acid,* is optically inactive and cannot be split into other forms. The isomerism of these four acids was exhaustively considered in the introduction. According to the theory of *van 't Hoff* and *Le Bel,* it is attributable to the presence of two asymmetric carbon atoms in the dihydroxyethylene succinic acid. A compound containing one asymmetric carbon atom may occur in three modifications—a dextro-form, a lævo-form, and, by union of these two, an inactive, decomposable [d+l] modification. If the same atoms or atomic groups are joined to two asymmetric carbon atoms,—that is, if the compound be symmetrically constructed, like hydroxyethylene succinic acid,—then in addition to the three modifications capable of forming a compound with one asymmetric carbon atom there arises a fourth possibility. Should the groups linked to the one asymmetric carbon atom (viewed from the point of union of the two asymmetric carbon atoms) show an opposite arrangement from that of the groups attached to the second asymmetric carbon atom, then an inactive body will result by virtue of an *internal compensation.* The action on polarized light occasioned by the one asymmetric carbon atom is equalized by an equally great but oppositely directed influence exerted by the second asymmetric carbon atom. (See also B. **35,** 4344.)

Therefore, the four symmetrical dihydroxysuccinic acids can be represented by the following formulæ, to which must be ascribed a spacial significance as basis (p. 32):



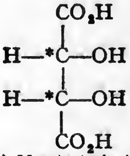
$$\begin{array}{c} CO_2H \\ | \\ H-{}^*C-OH \\ | \\ HO-{}^*C-H \\ | \\ CO_2H \end{array}$$

(1) Dextrotartaric Acid.



$$\begin{array}{c} CO_2H \\ | \\ HO-{}^*C-H \\ | \\ H-{}^*C-OH \\ | \\ CO_2H \end{array}$$

2) Lævotartaric Acid.



$$\begin{array}{c} CO_2H \\ | \\ H-{}^*C-OH \\ | \\ H-{}^*C-OH \\ | \\ CO_2H \end{array}$$

(3) Mesotartaric Acid.

d-Tartaric acid+l-tartaric acid=(4) Racemic Acid.

The configuration of d-tartaric acid, as represented on p. 646, follows in consequence of the formation of this acid from the oxidation of methyl tetrose, the decomposition product of rhamnose.

Historical.—Scheele in 1769 showed how this acid could be isolated from argol. *Kestner* in 1822 discovered *racemic acid* as a by-product in the manufacture of ordinary tartaric acid, and in 1826 *Gay-Lussac* investigated the two acids. He and later *Berzelius* (1830) proved that ordinary tartaric acid and racemic acid possessed the same composition, and this fact led *Berzelius* to introduce the term *isomerism* into chemical science (p. 25). *Biot* (1838) showed that a solution of ordinary tartaric acid rotated the plane of polarized light to the right, whereas the solution of racemic acid proved to be optically inactive, and was without action upon the polarized ray. *Pasteur's* classic investigations (1848–1853) demonstrated how racemic acid could be resolved into *dextro-* and *lævo-tartaric acid,* and be again re-formed from them. In addition to lævo-tartaric acid, *Pasteur* also discovered inactive or *mesotartaric acid,* which cannot be resolved. *Kekulé* in 1861 and, independently of him, *Perkin, Sr.*, and *Duppa* synthesized racemic acid and mesotartaric acid from succinic acid, derived from amber, through the ordinary dibromosuccinic acid. In 1873 *Jungfleisch* obtained racemic acid and mesotartaric acid from synthetic succinic acid, and also the other two tartaric acids derivable from racemic acid. *Van 't Hoff* in 1874 and, independently of him, *Le Bel* referred the isomerism of the four tartaric acids to the presence of two asymmetric carbon atoms in symmetrical dihydroxyethylene succinic acid. *Kekulé* and *Anschütz* in 1880 and 1881 found that when racemic acid was oxidized it yielded *fumaric acid,* and that inactive or mesotartaric acid gave maleïc acid.

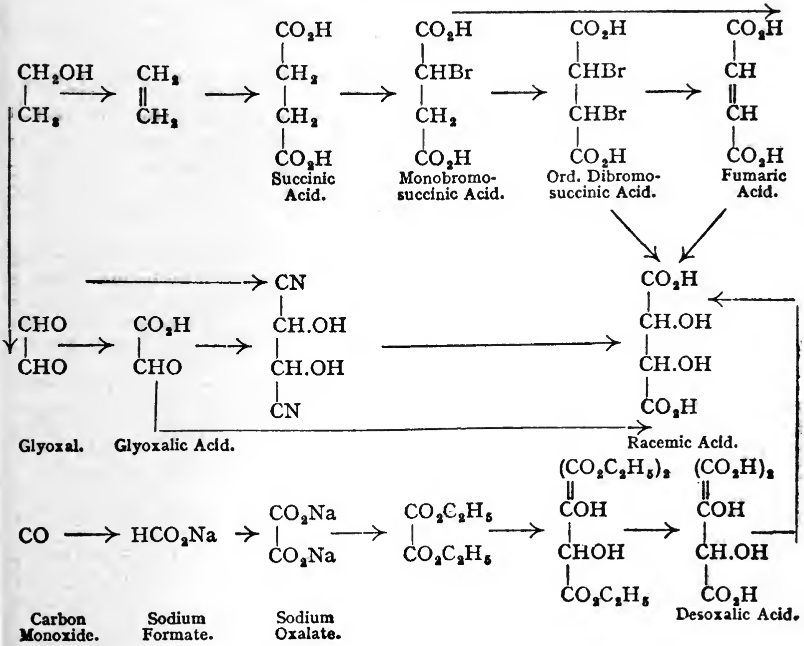
The oxidant was potassium permanganate. This reaction directly linked the isomerism of the tartaric acids to the isomerism of the two unsaturated acids—fumaric acid and maleïc acid.

(1) **Racemic Acid,** *Paratartaric Acid,* $C_4H_6O_6+H_2O$, m.p. 206° with decomposition (anhydrous), is sometimes found in conjunction with tartaric acid in the juice of the grape, and is formed in the preparation of ordinary tartaric acid, when the solution is evaporated over a flame, especially in the presence of alumina.

Racemic acid appears (1) in the oxidation of mannitol, dulcitol and mucic acid with nitric acid, as well as when fumaric acid (B. **13,** 2150), sorbic acid, and piperic acid are oxidized by potassium permanganate (B. **23,** 2772). It is synthetically obtained (2) from glyoxal by means of hydrocyanic and hydrochloric acids (together with mesotartaric acid, B. **27,** R. 749), and (3) from isodibromo- and (together with mesotartaric acid) from dibromosuccinic acid, by the action of silver oxide (pp. 501, 604); (4) together with glycollic acid (comp. the pinacone formation, p. 313), when glyoxylic acid is reduced with acetic acid and zinc; (5) by heating desoxalic acid with water to 100°, when carbon dioxide is split off.

Ethyl alcohol, which can be synthesized in various ways, constitutes the parent substance for the first four syntheses. In the fifth synthesis carbon monoxide serves for that purpose.

SYNTHESIS OF RACEMIC ACID



Racemic acid is also produced when equal quantities of concentrated solutions of dextro- and lævo-tartaric acids are mixed (B. **25,** 1566), and together with mesotartaric acid when ordinary tartaric acid is heated with water to 175°.

Properties.—Racemic acid crystallizes in rhombic prisms which slowly effloresce in dry air. It is less soluble (1 part in 5·8 parts at 15°) in water than the tartaric acid, and has no effect on polarized light. Potassium permanganate oxidizes it to oxalic acid, and hydriodic acid reduces it to inactive malic and ethylene succinic acids. Its *salts* closely resemble those of tartaric acid, but do not show hemihedral faces; the acid *potassium salt* is appreciably more soluble than cream of tartar; *calcium salt,* $C_4H_4O_6Ca+4H_2O$, dissolves with more difficulty than the corresponding salts of three other tartaric acids. Dilute acetic acid and ammonium chloride do not dissolve it. It is formed on mixing solutions of calcium dextro- and lævotartrates; *barium salt,* $C_4H_4O_6Ba+2\frac{1}{2}H_2O$, or $5H_2O$ (A. **292,** 311). Racemic changes of the racemates (B. **32,** 50, 857).

Optical Resolution of Racemic Acid.—When *Pasteur* was studying racemic acid he discovered methods for the decomposition of optically inactive bodies into their optically active components, which were briefly considered in the introduction (p. 57):

(1) *Penicillium glaucum,* growing in a racemic acid solution, destroys the dextro-tartaric acid, leaving the l-tartaric acid unattacked.

(2*a*) From a solution of sodium ammonium racemate the unaltered salt, without hemihedral faces, separates above +28° (B. **29,** R. 112). When the crystallization takes place below +28°, large rhombic crystals form, some of which show right, others left hemihedral faces. Removing the similar forms, or by testing a solution of the crystals with a solution of calcium dextro-tartrate (A. **226,** 193), the former will be found to possess dextro-rotatory power and yield common tartaric acid, whereas the latter yield the lævo-acid.

(2*b*) A solution of cinchonine racemate yields, on the first crystallization, the more sparingly soluble lævo-tartrate. If only half as much cinchonine, as is necessary for the production of the acid salt, be introduced, then two-thirds of the calculated quantity of cinchonine lævotartrate will separate (B. **29,** 42). Quinicine dextrotartrate is the first to crystallize from a solution of quinicine racemate.

Esters of Racemic Acid: *Dimethyl ester,* m.p. 85°, b.p. 282°, is produced from racemic acid, methyl alcohol, and HCl. It can be made by fusing together the dimethyl ester of dextro- and lævo-tartaric acids. It is obtained pure by distillation under reduced pressure. In vapour form it dissociates into the dimethyl ester of the dextro- and lævo-tartaric acids (B. **18,** 1397; **21,** R. 643).

Diacetyl Racemic Anhydride, $(C_2H_3O_2)_2C_4H_2O_3$, m.p. 123° (B. **13,** 1178). *Dimethyl Diacetyl Racemic Ester,* $(C_2H_3O_2)_2C_4H_2O_4(CH_3)_2$, m.p. 86°, results from the action of acetyl chloride on the dimethyl ester; and upon evaporating the benzene solution of the dimethyl-l- and d-diacetyl tartaric esters (A. **247,** 115). *Nitrile of Diacetyl Pyroracemic Acid,* $CH_3CO.OCH(CN).CH(CN)O.COCH_3$, m.p. 97°, is produced together with the nitrile of diacetyl mesotartaric acid, when acetic anhydride acts on the liquid portion of the additive product resulting from HNC and glyoxal in alcohol (B. **27,** R. 749).

Imides: *Methyl-, ethyl-,* and *phenyl-imides,* m.p. 157°, 179°, and 235° (B. **30,** 3040). The *anil* of diacetyl racemic acid, m.p. 94°, results when PCl_5 acts on the anilic acid, and when the *Anils* of d- and l-*Diacetyl Tartaric Acids,* m.p. 126°, combine (privately communicated by *Anschütz* and *Reitter*).

(2) **Dextro-rotatory or Ordinary Tartaric Acid** (*Acidum tartaricum*), m.p. 167–170° (B. **22**, 1814), is widely distributed in the vegetable world, and occurs principally in the juice of the grape, from which it deposits after fermentation in the form of potassium hydrogen tartrate (argol). It results on oxidizing methyl tetrose, saccharic acid, and lactose with nitric acid.

Ordinary tartaric acid crystallizes in large monoclinic prisms, which dissolve readily in water (1 part in 0·76 parts at 15°) and alcohol, but not in ether. Its solution rotates the ray of polarized light to the right, but a very concentrated aqueous solution at low temperatures turns it to the left (B. **32**, 1180). When it is heated with water to 165° it changes mainly to mesotartaric acid; at 175° the racemic acid predominates. Also, boiling with concentrated aqueous alkali converts d-tartaric acid partially into racemic and mesotartaric acids (B. **30**, 1574). It also forms racemic acid when it is brought together with a concentrated solution of l-tartaric acid. Pyroracemic and pyrotartaric acids (p. 50) are products of its dry distillation.

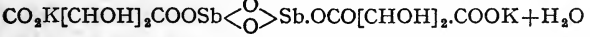
When gradually oxidized, d-tartaric acid becomes dihydroxyfumaric acid (p. 607), dihydroxytartaric acid, and tartronic acid (p. 549); stronger oxidizing agents decompose it into carbon dioxide and formic acid.

Hydriodic acid reduces it to d-malic and ethylene succinic acids.

d-Tartaric acid is applied in dyeing or colouring, as an ingredient of effervescing powders, and as a medicine. Nearly all of its salts meet with extended uses.

Salts. Tartrates.—The ***normal potassium salt***, $C_4H_4O_6K_2+\frac{1}{2}H_2O$, is readily soluble in water; from it acids precipitate the salt, $C_4H_5O_6K$, which is not very soluble in water, and constitutes natural *argol* (*Cremor tartari*); ***potassium sodium tartrate***, $C_4H_4O_6KNa+4H_2O$ (*Seignette salt*), crystallizes in large rhombic prisms with hemihedral faces; ***sodium ammonium salt***, $C_4H_4O_6Na(NH_4)+4H_2O$, is obtained from sodium ammonium racemate; ***calcium salt***, $C_4H_4O_6Ca+H_2O$, is precipitated from solutions of normal tartrates, by calcium chloride, as an insoluble, crystalline powder. It dissolves in acids and alkalis, and is reprecipitated as a jelly on boiling—a reaction serving to distinguish tartaric from other acids. (See also Calcium Racemate.)

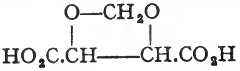
Lead salt, $C_4H_4O_6Pb$. *Copper salts* are not precipitated by alkali hydroxides in presence of tartaric acid. When cupric hydroxide is dissolved in tartaric acid and aqueous alkali, double salts are formed, such as cupric sodium ditartrate, $C_4H_2O_6CuNa_2+C_4H_2O_6Na_4+13H_2O$ (B. **32**, 2347). A solution of copper sulphate, rochelle salt, and sodium hydroxide is known as *Fehling's solution*, and is employed in the quantitative analysis of certain sugars (p. 628).

Tartar Emetic.—*Potassio-Antimonyl Tartrate, Tartarus emiticus, Tartarus stibiatus*, COOK.CHOH.CHOH.COOSbO$+\frac{1}{2}H_2O$, or $C_4H_4O_6{:}SbOK+\frac{1}{2}H_2O$, or  $CO_2K[CHOH]_2COOSb{<}\substack{O\\O}{>}Sb.OCO[CHOH]_2.COOK+H_2O$ (B. **16**, 2386), is prepared by boiling cream of tartar with antimony oxide and water. It crystallizes in rhombic octahedra, which slowly lose their water of crystallization on exposure and fall to a powder. It is soluble in fourteen parts of water at 10°. Its solution possesses an unpleasant metallic taste, and acts as an emetic. See B. **29**, R. 84; **28**, R. 463, for the corresponding arsenic compound.

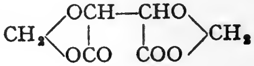
Dextro-tartaric Acid Esters, ROOC.CH(OH)CH(OH).COOR (comp. Racemic Esters), are obtained as follows: the acid is dissolved in methyl or ethyl alcohol, hydrochloric acid gas is passed through the solution, and the liquid is distilled under diminished pressure. PCl_5 converts them into esters of chloromalic acid (p. 605) and chlorofumaric acid. The esters constitute the first homologous series of optically active substances, of which the rotation of the plane of polarized light was investigated (*Anschütz* and *Pictet*, B. **13**, 1177; comp. B. **27**, R. 511, 621, 725, 729; B. **28**, R. 148; C. 1898, II. 17). *Dimethyl Ester*, m.p. 48°, b.p.$_{760}$ 280° $[\alpha]_D^{20}=+2{\cdot}16$. *Diethyl Ester*, fluid, b.p.$_{760}$ 280° $[\alpha]_D^{20}=+266$. *Di-n.-propyl Ester*, fluid, b.p.$_{760}$ 303° $[\alpha]_D^{20}=+12{\cdot}44$.

The action of iodo-alkyls and silver oxide is to produce ethers by substitution of the alcoholic hydroxyl groups of the tartaric esters. Thus, d-tartaric ester is converted by iodomethane and silver oxide into d-*Dimethoxysuccinic Dimethyl Ester*, $CH_3O_2C.CH(OCH_3)CH(OCH_3).CO_2CH_3$, m.p. 51°, b.p.$_{12}$ 132°, which, on hydrolysis with barium hydroxide solution, yields d-*Dimethoxysuccinic Acid*, m.p. 151°. These ether-esters are also produced from silver tartrate and iodo-alkyls. But if sodium ethoxide is present during reaction between tartaric esters and iodo-alkyls there results a mixture of sym.- and unsym.-dialkoxysuccinic esters (p. 566), which can also be produced by the action of sodium ethoxide on sym.-dibromosuccinic ester (C. 1900, I. 404; 1901, II. 401).

Mono- and *Di-formal Tartaric Acids.*


$$\begin{array}{c} \mathrm{O{-}CH_2O} \\ |\qquad\quad| \\ \mathrm{HO_2C.CH{-}{-}CH.CO_2H} \end{array}$$

and



(C. 1903, I. 136).

Diacetyl d-*Tartaric Anhydride* $(C_2H_3O)_2C_4H_2O_3$, m.p. 135°, is prepared by treatment of tartaric acid with acetic anhydride and a little sulphuric acid. Pyridine acetate at 0° produces the pyridine salt of hydroxymaleïc anhydride (p. 565). *Diacetyl Tartaric Dimethyl Ester*, m.p. 103°. *Diacetyl Tartaric Dianilide*, m.p. 214° (A. **279**, 138). *Diacetyl* d-*Tartaric Anil*; see Diacetyl Racemic Anil (p. 602). Other imides (B. **29**, 2710).

Nitrotartaric Acid, Dinitrotartaric Acid, $(NO_2O)_2C_2H_2(CO_2H)_2$, is obtained from tartaric acid by the action of nitric and sulphuric acids. It dissolves readily in alcohol and ether, and is insoluble in benzene and chloroform. $[\alpha]_D^{20}=+13{\cdot}5°$ in methyl alcohol. In aqueous solution the substance decomposes into dihydroxytartaric acid (p. 607), $CO_2H.C(OH)_2.C(OH)_2CO_2H$, which breaks down further into CO_2 and tartronic acid. *Dinitrotartaric Esters: Dimethyl Ester*, m.p. 75°; *diethyl ester*, m.p. 27°. *Mononitrotartaric esters*, $RO_2C.CH(ONO_2)$-$CH(OH).CO_2R$; *dimethyl ester*, m.p. 97°; *diethyl ester*, m.p. 47°. Both the series of compounds are formed together when tartaric esters are treated with nitric and sulphuric acids (C. 1903, I. 627; B. **36**, 778).

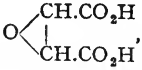
(3) **Lævo-Tartaric Acid**, m.p. 167–170°, is very similar to the dextro-variety, and only differs from it in rotating the ray of polarized light to the left. Their salts are very similar, and usually isomorphous, but those of the lævo-acid exhibit opposite hemihedral faces.

The dimethyl ester has the same melting and boiling points as the dimethyl ester of d-tartaric acid (see above); comp. also racemic acid esters (p. 602). In the description of racemic acid the method by which l-tartaric acid could be obtained from it was exhaustively considered (p. 602). In concentrated solution it combines with d-tartaric acid and yields racemic acid.

(4) **Inactive Tartaric Acid**, *Mesotartaric Acid, Antitartaric Acid*, is obtained when parasorbic acid and erythritol are oxidized with nitric acid, or (together with racemic acid) when dibromosuccinic acid is treated with silver oxide (p. 601); and maleïc acid or phenol with potassium permanganate (B. **24**, 1753). It is most readily prepared by heating common tartaric acid with water to 165° for two days. It contains one molecule of water of crystallization.

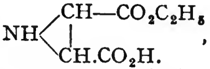
Calcium Salt, $C_4H_4O_6Ca+3H_2O$ (A. **226**, 198); *barium salt*, $C_4H_4O_6Ba$-$+H_2O$ (A. **292**, 315); *dimethyl ester*, m.p. 111°; *diethyl ester*, m.p. 54°, b.p.$_{14}$ 156° (B. **21**, 517). *Mesotartaronitrile*, $CN.CH(OH).CH(OH)CN$, m.p. 131° with decomposition, is produced by the addition of hydrocyanic acid to glyoxal, dissolved in alcohol. *Diacetyl Mesotartaronitrile*, m.p. 76° (B. **27**, R. 749).

Chloromalic Acid, *a-Chloro-β-hydroxy-succinic Ester*, $HO_2C.CH(OH)CHCl.CO_2H$, m.p. 143°, and **Bromomalic Acid**, m.p. 134°, are obtained from fumaric or maleïc acid by the addition of HClO or HBrO (in the form of chlorine or bromine water). When heated they decompose into water and chloro- and bromo-maleïc acids; when boiled with water they break down into CO_2, the halogen acid, aldehyde, and a mixture of racemic and mesotartaric acid. The acids are optically inactive. If, however, d-tartaric ester is treated with PCl_5 or PBr_3, l-*chloromalic ester* and l-*bromomalic ester* result (B. **28**, 1291; A. **348**, 273).

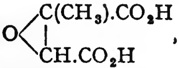
Ethylene Oxide Dicarboxylic Acid, Fumaryl Glycidic Acid,  $O\Big\langle\begin{matrix}CH.CO_2H\\ |\\ CH.CO_2H\end{matrix}$, m.p. 203°, is prepared from chloro- and bromo-malic acid by aqueous sodium hydroxide; HBr and HCl regenerate the original acids. When boiled with water it breaks down into racemic and mesotartaric acids; *dimethyl ester*, m.p. 73°; *diamide*, m.p. 225° with decomposition; *dichloride*, m.p. 53°, b.p.$_{40}$ 90–93° (A. **348**, 299).

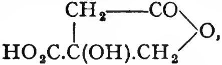
Diaminosuccinic Acid, $CO_2H.CH(NH_2)CH(NH_2).CO_2H$, is formed when the diphenylhydrazone of dioxosuccinic acid (p. 608) is reduced with sodium amalgam. The one acid corresponds with mesotartaric acid (p. 604), the other with racemic acid (p. 601), as has been proved by conversion into these acids; *diethyl ester*, b.p.$_{15}$ 160–165°. *Diacetyl Diaminosuccinic Diethyl Ester*, m.p. 180° (B. **38**, 1589). Reaction with one molecule of nitrous acid produces *Hydroxyamino-succinic Acid*, $HO_2C.CH(NH_2)CH(OH).CO_2H$, m.p. 314–318° (C. 1905, I. 1890; see also A. **348**, 307).

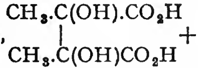
Dianilinosuccinic Ester, $CO_2C_2H_5.CH(NHC_6H_5)CH(NHC_6H_5).CO_2C_2H_5$, m.p. 149°, is obtained from dibromo- and isodibromo-succinic ester and alcoholic aniline heated to 100° (B. **27**, 1604).

Iminosuccinic Monoethyl Ester,  $NH\Big\langle\begin{matrix}CH—CO_2C_2H_5\\ |\\ CH.CO_2H.\end{matrix}$, m.p. 98°, is prepared from iminosuccinic monoester amide, a product of the reaction of alcoholic ammonia and dibromosuccinic ester (B. **25**, 646).

Azinsuccinic Ester, $(CO_2C_2H_5)_2C_2H_2.N_2.C_2H_2(CO_2C_2H_5)$, is obtained from diazoacetic ester; an isomeric ester is obtained from diazosuccinic ester (B. **29**, 763).

Oxycitraconic Acid,  $O\Big\langle\begin{matrix}C(CH_3).CO_2H\\ |\\ CH.CO_2H\end{matrix}$, decomposes at 162°. It is formed when *a-Chlorocitramalic Acid*, m.p. 139°, the addition product of HClO and citraconic acid, is treated with alkali hydroxide. Hydrochloric acid changes it to *β-Chlorocitramalic Acid*, m.p. 162° with decomposition (A. **253**, 87).

Hydroxyparaconic Acid,  $\begin{matrix}CH_2——CO\\ |\\ HO_2C.C(OH).CH_2\end{matrix}\Big\rangle O$, m.p. 104°, is prepared from itaconic acid (p. 515) and potassium permanganate.

Dimethyl Racemic Acid,  $\begin{matrix}CH_3.C(OH).CO_2H\\ |\\ CH_3.C(OH)CO_2H\end{matrix}$ $+H_2O$, m.p. 178° with decomposition, is formed (1) from pyroracemic acid (p. 407) by reduction (B. **25**, 397), and (2) from diacetyl (p. 349) by the action of HNC and hydrochloric acid (B. **22**, R. 137).

C. Glutaric Acid Derivatives.

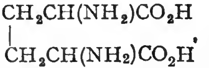
aβ-Dihydroxyglutaric Acid, $HO_2C.CH(OH)CH(OH)CH_2.CO_2H$, m.p. 158°, is formed from the bromine addition product of glutaconic acid, or from the latter by permanganate. An optically active form of this acid has been obtained by the break-down of metasaccharopentose (p. 620) (B. **38**, 3625).

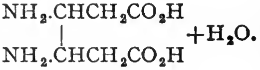
aγ-Dihydroxyglutaric Acid, $HO_2C.CH(OH)CH_2CH(OH)CO_2H$, m.p. 120°; *lactone acid*, m.p. 165°, is formed from *aγ*-dihydroxypropane *aaγ*-tricarboxylic acid (the oxidation product of isosaccharine, p. 620) by loss of CO_2 (B. **18**, 2576; **38**, 3624).

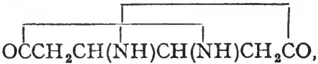
αγ-Dihydroxy-αγ-dimethyl-glutaric Acids,  $\frac{HO_2C}{CH_3}>C(OH)CH_2C(OH)<\frac{CO_2H}{CH_3}$, exists in two modifications, both of which are prepared from acetyl acetone and hydrocyanic acid (B. **24**, 4006; **25**, 3221). The one, m.p. 98°, is obtained in enantiomorphous crystals from ether; the other readily passes into the *lactonic acid*, m.p. 90°, which, when heated, forms a *dilactone*, m.p. 105°, b.p. 235°, *αβ-Dihydroxy-γγ-dimethyl-glutaric Lactonic Acid* (p. 570); *αγ-Dihydroxy-ββ-dimethyl-glutaric Acid*, $(CH_3)_2C[CH(OH)CO_2H]_2$; *lactonic acid*, m.p. 146° (C. 1901, II. 109); *αγ-Dihydroxy-* and *βγ-trimethyl-glutaric Acid* (B. **28**, 2940).

D. Adipic Acid Derivatives and Higher Homologues.

αα-Dihydroxyadipic Acid, $HO_2C.CH(OH)CH_2CH_2CH(OH)CO_2H$, exists in two forms which are produced from the corresponding *αα-Dibromadipic Acids*, m.ps. 139° and 193°, which occur together after the bromination of *adipic acid chloride* (C. 1908, I. 2021). The *racemic form*, m.p. 146°, is resolved by means of cinchonidine, and when heated yields a *dilactone*,  $OCOCHCH_2CH_2CHCOO$, m.p. 134°; *meso-form*, m.p. 173°, is not resolvable, and when heated gives a *lactone lactide*.

αα₁-Diaminoadipic Acid,  $\begin{matrix}CH_2CH(NH_2)CO_2H\\ |\\ CH_2CH(NH_2)CO_2H\end{matrix}$, decomposes at 275°, is prepared by decomposition of ethylene bis-phthalimidomalonic ester, a product of reaction of ethylene bromide and sodium phthalimidomalonic ester (p. 550). Similarly, *αα₁-diaminopimelic acid* is formed from trimethylene bis-phthalimidomalonic ester (C. 1908, II. 682).

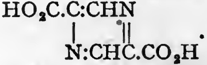
ββ₁-Diaminoadipic Acid,  $\begin{matrix}NH_2.CHCH_2CO_2H\\ |\\ NH_2.CHCH_2CO_2H\end{matrix}+H_2O$.

The *dilactam*,  $OCCH_2CH(NH)CH(NH)CH_2CO$, m.p. 275°, is formed by heating muconic acid or muconic amide (p. 522) with ammonia to 135–150°; also by reduction of dicyanodimalonic ester, $(RO_2C)_2.CHC(NH).C(NH)CH(CO_2R)_2$ (p. 655), and subsequent hydrolysis and abstraction of CO_2 (B. **36**, 172).

αα₁-Diaminosuberic Acid, αα₁-Diaminosebacic Acid, αα₁-Diaminoazelaïc Acid, are prepared from the corresponding dicarboxylic acid by bromination and reaction with two molecules of NH_3. When heated they break down into CO_2 and alkylene diamines (p. 333) (C. 1905, II. 462; 1906, II. 764). *Dimethyl Dihydroxyadipic Acids* are formed from acetonyl acetone and hydrocyanic acid (B. **29**, 819). *Cineolic Acid*, $C_{10}H_{16}O_5$, is the anhydride of α-hydroxyisopropyl α-methyl α-hydroxy-adipic acid, comparable to the alkylene oxides (see Cineol, Vol. II.).

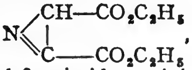
Dihydroxysuberic Acid and *Dihydroxysebacic Acid*; see Adipic Dialdehyde and Suberic Dialdehydes (p. 348) (C. 1905, II. 462; 1907, II. 1236).

Dihydroxy-olefine-carboxylic Acids.

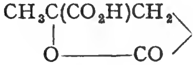
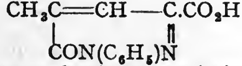
Dihydroxymaleïc Acid, $HO_2C.C(OH):C(OH).CO_2H+2H_2O$, may perhaps be looked on as being *oxalohydroxyacetic acid*, $HO_2CCO.CH(OH)CO_2H$ (A. **357**, 291). It is formed when tartaric acid is oxidized with hydrogen peroxide in presence of small quantities of ferrous salts in sunlight. A warm solution of HBr in glacial acetic acid converts it into an isomeric body, probably dihydroxyfumaric acid. When heated with water it decomposes into $2CO_2$ and *glycol aldehyde*; ammonia produces *Pyrazine Dicarboxylic Acid*,  $\begin{matrix}HO_2C.C:CHN\\ | \quad \|\\ N:CHC.CO_2H\end{matrix}$.
Oxidation of the sodium salt of dihydroxymaleïc acid with bromine in acetic acid gives rise to sodium dihydroxytartrate (p. 608); whilst oxidation with ferric salts produces glyoxyl carboxylic acid (p. 545) (C. 1905, II. 456). *Diacetyl Dihydroxymaleïc Acid*, m.p. 98°. See also *Dichloro-* and *Dibromo-maleïc Acids*, and their decomposition products (p. 514) (B. **38**, 258).

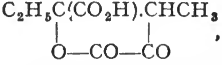
11. HYDROXY-KETO-DICARBOXYLIC ACIDS.

Ethoxyoxalacetic Ester, $C_2H_5O_2C.COCH(OC_2H_5)CO_2C_2H_5$, b.p.$_{11}$ 155°, is prepared from oxalic ester and ethyl glycollic ester. When distilled under ordinary pressure it gives ethoxymalonic ester (B. **31**, 552). See also Dihydroxymaleïc Acid (above).

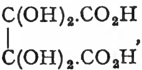
Nitrilosuccinic Dimethyl Ester, 
$N \lessgtr \begin{matrix} CH—CO_2C_2H_5 \\ | \\ C——CO_2C_2H_5 \end{matrix}$, b.p.$_{40}$ 154°, is produced by the reaction of the silver salt of β-oximidosuccinic ester (p. 567) and iodoethane and subsequent distillation (B. **23**, R. 561; **24**, 2289).

Glycolyl Malonic Acid; *γ-Hydroxyacetoacetic α-Carboxylic Acid*, $HOCH_2\text{-}COCH(CO_2H)_2$, is a hypothetical acid, from which is derived *Tetronic α-Carboxylic ester*, $\overline{OCH_2COCH(CO_2R)CO}$; *methyl ester*, m.p. 172° with decomposition; *ethyl ester*, m.p. 125°. The substances are prepared from sodium malonic ester and acetyl glycollic chloride or chloracetyl chloride, of which the desmotropic *aci-form*, $\overline{OCH_2C(OH){:}C(CO_2R)CO}$, are strong acids like tetronic acid itself (p. 544) into which they pass on hydrolysis and loss of CO_2. Sodium cyanacetic ester and chloracetyl chloride produce *Chloracetyl Cyanacetic Ester*, $ClCH_2COCH(CN)CO_2R$; *methyl ester*, m.p. 73°; *ethyl ester*, 43°. The *silver salt* and iodoethane yield the O-*ethyl ether* of the aci-form, $ClCH_2C(OC_2H_5){:}\text{-}C(CN)CO_2C_2H_5$, m.p. 94°, which with ammonia gives the *amino*-compound, $ClCH_2.C(NH_2){:}C(CN)CO_2CH_5$, m.p. 129°. The sodium salt of chloracetyl cyanacetic ester, however, reacting with ammonia forms a lactone—*Cyanoketopyrrolidone*, $\overline{NHCH_2COCH(CN)CO}$, m.p. 221° with decomposition (B. **41**, 2399). Homologous with the tetronic carboxylic esters is *Carbotetrinic Ester*, $\overline{OCH_2COCH(CH_2CO_2C_2H_5)CO}$, m.p. 96°, which results from distillation of bromacetosuccinic ester.

α-Keto-γ-valerolactone γ-Carboxylic Acid, 
$\begin{matrix} CH_3C(CO_2H)CH_2 \\ | \\ O——CO \end{matrix} \rangle CO$, m.p. 117°, results from the spontaneous decomposition of pyroracemic acid (p. 407), or more quickly under the influence of hydrochloric acid. It reacts also in the tautomeric enol-form, yielding *a-phenylhydrazone*, which, on cleavage of the lactone ring and loss of water passes into *phenyl methyl pyridazone carboxylic acid*, 
$\begin{matrix} CH_3C{=\!=}CH—C.CO_2H \\ | \qquad\qquad \| \\ CON(C_6H_5)N \end{matrix}$ (Vol. II.). Alcoholic hydrochloric acid converts the keto-valerolactone acid into *γ-Methyl Ketoglutaconic Ester*, $CH_3C(CO_2C_2H_5){:}\text{-}CH.COCO_2C_2H_5$, b.p.$_{28}$ 183°, whilst hot strong hydrochloric acid produces pyrotartaric acid (p. 493) (A. **317**, 1; **319**, 121; C. 1902, II. 508; 1904, II. 193).

α-Keto-β-methyl-γ-caprolactone-γ-carboxylic Acid, 
$\begin{matrix} C_2H_5C(CO_2H).CHCH_3 \\ | \qquad\qquad | \\ O—CO—CO \end{matrix}$, m.p. 128°, is produced from α-methyl oxalacetic ester (p. 567) by 70–80 per cent. sulphuric acid (B. **35**, 1626).

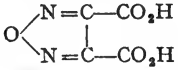
12. DIKETONE DICARBOXYLIC ACIDS

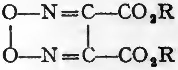
Dihydroxytartaric Acid, 
$\begin{matrix} C(OH)_2.CO_2H \\ | \\ C(OH)_2.CO_2H \end{matrix}$, m.p. 98° with decomposition, is obtained (1) when protocatechuic acid, pyrocatechin, or guaiacol (Vol. II.), in ethereal solution, is acted on with nitrous acid; (2) by oxidation of dihydroxymaleïc acid; and (3) by spontaneous decomposition of nitrotartaric acid (see A. **302**, 291, footnote).

It was formerly regarded as carboxytartronic acid, $C(OH)(CO_2H)_3$. Its formation from the benzene derivatives just cited is proof for the assumption that in benzene *one* carbon atom is combined with *three* other carbon atoms. However, *Kekulé* removed the basis from this assumption when he showed that the body supposed to be carboxytartronic acid could also be made from nitrotartaric acid by the action of an alcoholic solution of nitrous acid, and then by reduction be converted into racemic and mesotartaric acids. He therefore named it dihydroxytartaric acid, for it sustains the same relation to tartaric acid that glyoxylic acid bears to glycollic acid, and mesoxalic acid to tartronic acid (A. **221**, 230). Glyoxal is formed when sodium dihydroxytartrate is acted on with sodium hydrogen sulphite. The *sodium salt*, $C_4H_4O_8Na_2+2H_2O$, is a sparingly soluble crystalline powder, which can be employed for precipitating the acid and for the estimation of sodium (C. 1898, I. 688). Other salts (C. 1898, II. 276; 1905, II. 397).

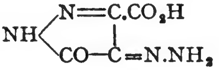
The *dihydroxytartaric esters* are not known. *Dihydroxyketosuccinic Diethyl Ester*, $CO_2C_2H_5.C(OH)_2CO.CO_2C_2H_5$, m.p. 116°, is, however, known, consisting of colourless crystals, produced on adding water to *Diketosuccinic Diethyl Ester*, $CO_2C_2H_5.COCO.CO_2C_2H_5$, b.p. 230°, b.p.$_{18}$ 116°, $D_{20}=1{\cdot}1896$, and subsequent distillation under diminished pressure. Hydrochloric acid acting on sodium dihydroxytartaric acid suspended in alcohol produces the dioxosuccinic diethyl ester. It is a thick liquid with an orange-yellow colour (B. **25**, 1975) (comp. *a*-diketones, p. 349). When it is boiled under a reflux condenser CO splits off, and oxomalonic ester (p. 563) and oxalic ester result (B. **27**, 1304).

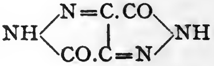
Oximes. *Dioximidosuccinic Acid*, $HO_2C.C(NOH)C(NOH).CO_2H$, and its *esters* have been obtained in different stereomeric forms (C. 1908, I. 1042, etc.). The *dioxime anhydride, Furazan Dicarboxylic Acid* (1) is prepared by oxidation of dimethyl furazan (comp. p. 355); the *dioxime peroxide* of the ester (2) from isonitroso-acetic ester (p. 405) or isonitroso-acetoacetic ester (p. 546) and nitric acid. It is an easily decomposable oil (B. **28**, 1213).

(1)


(2)


Hydrazones. *Hydrazone Pyrazolone Carboxylic Acid* (1) and *Pyrazolonopyrazolone* (2) may be taken as being the *lactazam* and *dilactazam* (comp. p. 406) of the *mono-* and *dihydrazone* of diketosuccinic acid (see Vol. II.).

(1)


(2)


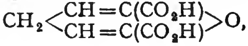
Diketosuccinic Ester Monophenylhydrazone, $C_6H_5NH.N{:}C(CO_2C_2H_5).CO.CO_2C_2H_5$, m.p. 73°, is formed from oxalacetic ester (p. 566) and diazobenzene. It is converted into the *stereomeric Hydrazone*, m.p. 127°, by sodium alcoholate (C. 1904, I. 580). The *osazone* of diketosuccinic acid readily passes into the *lactazam, Phenylhydrazone Phenylpyrazolone Carboxylic Acid*, $C_6H_5N.N{:}C(CO_2H)C(NNHC_6H_5).CO$, the basis of the dye *tartrazine*. *Diketosuccinic Diethyl Ester Osazone* $[C_6H_5NHN{:}C(CO_2C_2H_5)]_2$ is known in *three* modifications, *a*-, m.p. 121°; *β*-, m.p. 137°; *γ*-, m.p. 175°. The *a*-form gradually passes spontaneously into the *β*-substance, a change which is accelerated by iodine or sulphur dioxide. All three forms are readily converted into pyrazolone compounds.

Oxalodiacetic Acid, *Ketipic Acid*, $HO_2CCH_2.COCO.CH_2CO_2H$, is precipitated from the ester by concentrated hydrochloric acid, as a white insoluble powder. Heat decomposes it into $2CO_2$ and diacetyl. The *ester*, $C_2H_5O_2CCH_2.COCO.CH_2CO_2C_2H_5$, m.p. 77°, is prepared, similarly to oxalacetic ester (p. 566) from a mixture of oxalic ester and two molecules of acetic ester by the action of sodium (B. **20**, 591); also, from oxalic ester and chloracetic ester and zinc (B. **20**, 202). An alcoholic solution of the ester is given an intense red coloration by ferric chloride. Chlorine and bromine produce *tetrachlor-* and *tetrabrom-oxalodiacetic ester*. The first, known as *Tetrachlorodiketoadipic Ester*, is also obtained by the action of chlorine on dihydroxyquinone dicarboxylic ester (B. **20**, 3183). The osazone of oxalodiacetic ester can be converted into *di-1-phenyl-3,3-bis-pyrazolone* (Vol. II.) (B. **28**, 68).

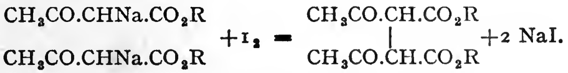
a-Oxalacetoacetic Ester, $HO_2CCO.CH(COCH_3)CO_2H$, is not known, but a derivative, *a-Cyaniminomethylacetic Ester*, $NCC(NH)CH(COCH_3)CO_2C_2H_5$, m.p. 122°, has been prepared from dicyanogen and acetoacetic ester by the action of sodium ethoxide (comp. p. 417). Acids or secondary amines convert it into the various possible desmotropic modifications of the enol type, into two isomeric forms, m.ps. 178° and 211°, and with absorption of water into *α-acetyl β-iminosuccinamic ester*, and finally into *α-acetyl β-iminosuccinimide* (A. **332**, 104).

γ-Oxalo-α-dimethyl-acetoacetic Ester, $C_2H_5O_2C.CO.CH_2COC(CH_3)_2CO_2C_2H_5$, is obtained by condensing oxalic ester and α-dimethyl acetoacetic ester. When distilled under ordinary pressure there is a partial loss of CO. The *free acid*, m.p. 180° with decomposition, into CO_2 and $(CH_3)_2CHCO.CH_2COCO_2H$. *Oxalodimethyl-acetoacetic Ester*, $C_2H_5O_2C.CO.CH_2C(C_2H_5)_2CO_2C_2H_5$, b.p. 275–285° with decomposition, into CO and α-dimethyl acetone dicarboxylic ester (p. 569). These esters are in general similar to oxalacetic ester (B. **33**, 3432).

δε-Oxalolævulinic Acid, γε-Diketopimelic Acid, $HO_2C.CO.CH_3COCH_2CH_2CO_2H$, m.p. 100–125°, is obtained from its *ethyl ester*, m.p. 19°, the condensation product of oxalic ester and lævulinic ester by warming the two esters with sulphuric acid. When heated the acid breaks down into CO_2, CO, and lævulinic acid. Reduction produces n.-pimelic acid (B. **31**, 622).

αα₁-Diketopimelic Acid, $CH_2(CH_2COCO_2H)_2$, m.p. 127°, is obtained from methylene bis-oxalacetic ester by hydrolysis and loss of CO_2. When treated with dehydrating agents there is formed *Pyran Dicarboxylic Acid*,  $CH_2<\begin{matrix}CH=C(CO_2H)\\CH=C(CO_2H)\end{matrix}>O$, decomposes at 250° (Vol. II.) (C. 1904, II. 602).

sym.-*Diacetyl-* or *Diacetosuccinic Acid*, $C_8H_{10}O_6$; *ethyl ester* is formed by electrolysis or the action of iodine on sodium acetoacetic ester (A. **201**, 144; B. **28**, R. 452):

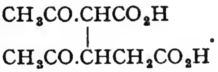


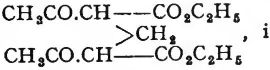
$$\begin{matrix}CH_3CO.CHNa.CO_2R\\CH_3CO.CHNa.CO_2R\end{matrix}+I_2=\begin{matrix}CH_3CO.CH.CO_2R\\|\\CH_3CO.CH.CO_2R\end{matrix}+2\,NaI.$$

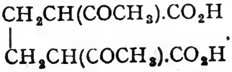
Theory demands the existence of 13 isomeric forms of this body—two optically active, and two optically inactive keto-forms, three cis-trans isomers of the double enol-form, and four optically active and two racemic mixed keto-enol-forms. Of the seven optically inactive modifications, five are known: β and γ-keto-forms, m.ps. 90° and 68°; α_1-, α_2-, and α_3-enol-forms, m.ps. liquid, 21° and 31° (A. **306**, 332). When heated or acted on by acids, diacetosuccinic ester is converted into carbopyrotritaric ester (a derivative of furfurane); ammonia and the amines produce pyrrole derivatives—a reaction which serves to identify the substance (B. **19**, 46). Phenylhydrazine reacts as it does with acetoacetic ester, forming a bis-pyrazolone derivative (A. **238**, 168).

When boiled with potash solution the ester undergoes the ketonic change into CO_2 and acetonyl acetone (p. 350).

unsym.-*Diacetosuccinic Ester*, $(CH_3CO)_2C(CO_2C_2H_5)CH_2CO_2C_2H_5$, b.p. 275, is formed from sodium acetosuccinic ester and acetyl chloride (J. pr. Ch. [2] **65**, 532).

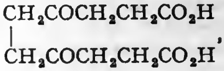
αβ-Diacetoglutaric Acid,  $\begin{matrix}CH_3CO.CHCO_2H\\|\\CH_3CO.CHCH_2CO_2H\end{matrix}$. Its diethyl ester is obtained from sodium acetoacetic ester and β-bromolævulinic ester (p. 423). Being a γ-diketone compound, it unites with ammonia and forms a pyrrole derivative (B. **19**, 47).

αγ-Diacetoglutaric Ester,  $\begin{matrix}CH_3CO.CH—CO_2C_2H_5\\>CH_2\\CH_3CO.CH—CO_2C_2H_5\end{matrix}$, is formed from formaldehyde and acetoacetic ester in the presence of small quantities of a primary or secondary amine (*Knoevenagel*, A. **288**, 321; B. **31**, 1388). It passes readily into a tetrahydrobenzene derivative. The β-alkyl-αγ-diacetoglutaric esters prepared from the homologous aldehydes behave in a similar manner.

αδ-Diaceto-adipic Acid,  $\begin{matrix}CH_2CH(COCH_3).CO_2H\\|\\CH_2CH(COCH_3).CO_2H\end{matrix}$. Ethylene bromide acting on two molecules of sodium acetoacetic ester, forms its diethyl ester. Phenylhydrazine converts it into a bis-pyrazolone derivative (B. **19**, 2045).

Diaceto-dimethyl-pimelic Acid (B. **24**, R. 729).

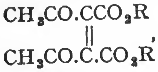
Dilævulinic Acid, [4,7-Decane dione diacid,]



$$\begin{array}{l}CH_2COCH_2CH_2CO_2H\\ |\\ CH_2COCH_2CH_2CO_2H\end{array}$$

, results when alcoholic hydrochloric acid acts on δ-furfural lævulinic acid (A. **294**, 167).

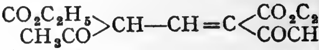
Iodine converts disodium diacetosuccinic ester into *diacetofumaric ester,*



$$\begin{array}{l}CH_3CO.CCO_2R\\ \quad\quad\ \ \|\\ CH_3CO.C.CO_2R\end{array}$$

, m.p. 96° (B. **30**, 1991).

Methenyl Bis-acetoacetic Ester,



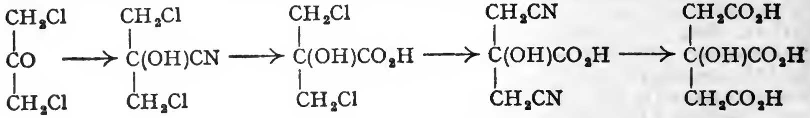
$$\begin{array}{l}CO_2C_2H_5\\ CH_3CO\end{array}\!\!>CH—CH=C\!<\!\!\begin{array}{l}CO_2C_2H_5\\ COCH_3\end{array}$$

—see ethoxymethylene acetoacetic ester (p. 546).

13. HYDROXYTRICARBOXYLIC ACIDS

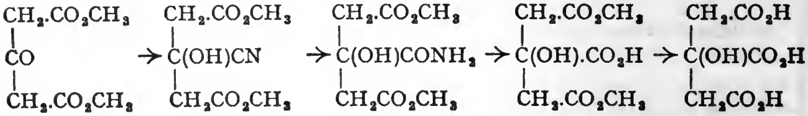
Citric Acid, *Hydroxytricarballylic Acid* (*Acidum citricum*), CO_2H-$CH_2.C(OH)(CO_2H).CH_2CO_2H+H_2O$, m.p. (anhydrous) 153°, occurs free in lemons, in currants, in cranberries, in beets, and in other acid fruits. It is obtained on a commercial scale from lemon juice, and by the action of certain ferments, such as *Citromycetes pfefferianus* and *glaber* (B. **26**, R. 696; **27**, R. 78, 448).

The acid can be prepared synthetically from β-dichloracetone; this is accomplished by first acting on the latter compound with hydrocyanic acid and hydrochloric acid, whereby dichlorohydroxyisobutyric acid is formed, which is then treated with potassium cyanide producing a cyanide, which is hydrolyzed with hydrochloric acid:



$$\begin{array}{l}CH_2Cl\\ |\\ CO\\ |\\ CH_2Cl\end{array}\longrightarrow\begin{array}{l}CH_2Cl\\ |\\ C(OH)CN\\ |\\ CH_2Cl\end{array}\longrightarrow\begin{array}{l}CH_2Cl\\ |\\ C(OH)CO_2H\\ |\\ CH_2Cl\end{array}\longrightarrow\begin{array}{l}CH_2CN\\ |\\ C(OH)CO_2H\\ |\\ CH_2CN\end{array}\longrightarrow\begin{array}{l}CH_2CO_2H\\ |\\ C(OH)CO_2H\\ |\\ CH_2CO_2H\end{array}$$

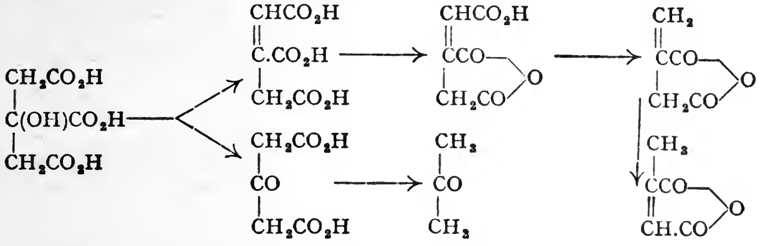
Further, citric acid is formed from acetone dicarboxylic ester, $CO(CH_2.CO_2R)_2$ (p. 568), by the action of HNC and hydrochloric acid: sym.-citric dimethyl ester amide and sym.-citric dimethyl di-ester (p. 611) are obtained as intermediate substances:



$$\begin{array}{l}CH_2.CO_2CH_3\\ |\\ CO\\ |\\ CH_2.CO_2CH_3\end{array}\rightarrow\begin{array}{l}CH_2.CO_2CH_3\\ |\\ C(OH)CN\\ |\\ CH_2CO_2CH_3\end{array}\rightarrow\begin{array}{l}CH_2.CO_2CH_3\\ |\\ C(OH)CONH_2\\ |\\ CH_2CO_2CH_3\end{array}\rightarrow\begin{array}{l}CH_2.CO_2CH_3\\ |\\ C(OH).CO_2H\\ |\\ CH_2.CO_2CH_3\end{array}\rightarrow\begin{array}{l}CH_2.CO_2H\\ |\\ C(OH)CO_2H\\ |\\ CH_2CO_2H\end{array}$$

Properties.—Citric acid crystallizes in large rhombic prisms, which dissolve in 4 parts of water of 20°, the anhydrous acid crystallizes mostly anhydrous from its solutions (B. **36**, 3599). It readily dissolves in alcohol and with difficulty in ether. The aqueous solution is not precipitated by milk of lime when cold, but on boiling the tertiary calcium salt separates, which is insoluble, even in potassium hydroxide solution (see Tartaric Acid).

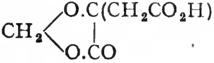
When heated to 175° citric acid decomposes into aconitic acid (p. 594). Rapidly heated to a higher temperature aconitic acid breaks down into water and its anhydride acid, which changes to CO_2 and *itaconic anhydride,* and the latter in part to *citraconic anhydride* (B. **13,** 1541). Another portion of the citric acid loses water and CO_2, becoming converted thereby into acetone dicarboxylic acid, which immediately splits into $2CO_2$ and acetone :



It breaks up into acetic and oxalic acids when fused with potassium hydroxide, and by oxidation with nitric acid. Acetone dicarboxylic acid (p. 568) is produced when citric acid is digested with concentrated sulphuric acid, and when oxidized with permanganate (C. 1900, I. 328).

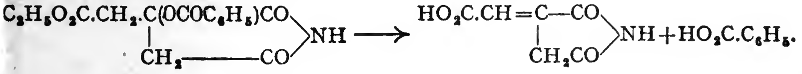
Salts.—Being a tribasic acid it forms three series of salts, and also two different mono- and two different di-alkali salts (B. **26,** R. 687).

The *calcium salt,* $(C_6H_5O_7)_2Ca_3+4H_2O$, is precipitated on boiling.

Esters.—*Trimethyl Ester,* m.p. 79°, b.p.$_{18}$ 176°; *dimethyl ester, citric dimethyl acid ester,* $CH_2(CO_2CH_3)C(OH)(CO_2H)CH_2CO_2CH_3$, m.p. 126°, is formed by partial esterification of the acid. It crystallizes with 1 molecule of water and is difficultly soluble in cold water (B. **35,** 2085). *Acetocitric Trimethyl Ester,* b.p.$_{15}$ 171°, is decomposed by distillation at ordinary pressures into acetic acid and aconitic ester (B. **18,** 1954). sym.-*Acetocitric Dimethyl Acid Ester,* m.p. 75°; *amide,* m.p. 109° (B. **38,** 3194). *Acetocitric Anhydride,* m.p. 121° (B. **22,** 984), decomposes on distillation at ordinary pressures into CO_2, acetic acid, and citraconic anhydride. *Methylene Citric Acid,*  $CH_2\left<\begin{array}{l}O.C(CH_2CO_2H)_2\\ \quad | \\ O.CO\end{array}\right.$, m.p. 208°, is prepared from citric acid, formaldehyde, and hydrochloric acid; or from formaldehyde derivatives (C. 1902, I. 299, 738; 1908, I. 1589).

Methoxycitric Acid, $(CH_3O)C(CO_2H)(CH_2CO_2H)_2$, m.p. 131°; *trimethyl ester,* b.p.$_{12}$ 165°, is prepared from citric trimethyl ester, iodomethane, and silver oxide (A. **327,** 228).

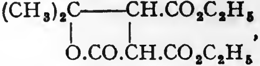
Citramide, $C_3H_4(OH)(CONH_2)_3$, when heated with hydrochloric or sulphuric acid, is condensed to *citrazinic acid,* sym.-*aconitimide acid, dihydroxypyridine carboxylic acid* (p. 595) (B. **17,** 2687; **23,** 831; **27,** R. 83). sym.-*Citric Dimethyl Ester Amide,* $NH_2OC.C(OH)(CH_2O_2CH_3)_2$, m.p. 107°, is prepared from the *nitrile, Acetone Dicarboxylic Ester Cyanhydrin,* m.p. 53°, and reacts in concentrated sulphuric acid with sodium nitrite to form sym.-citric dimethyl ester (p. 610). *Benzoyl Citrimide Ethyl Ester,* m.p. 115°, is prepared from *Citric Diethyl Ester Amide,* m.p. 74°, and benzoyl chloride. It is decomposed in the cold by aqueous sodium hydroxide into benzoic acid and asym.-aconitimido-acid (p. 595) which is isomeric with citrazinic acid (see above) (B. **38,** 3193):



$$\begin{array}{l}C_2H_5O_2C.CH_2.C(OCOC_6H_5)CO \\ \qquad | \\ \qquad CH_2\text{———}CO\end{array}\!\!>NH \longrightarrow \begin{array}{l}HO_2C.CH{=}C{-}CO\\ \qquad | \\ \qquad CH_2CO\end{array}\!\!>NH+HO_2C.C_6H_5.$$

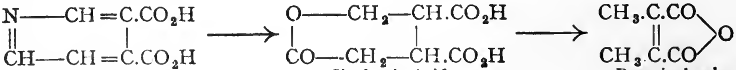
Isocitric Acid, $CO_2H.CH(OH).CH(CO_2H).CH_2CO_2H$ (see Trichloromethyl Paraconic Acid, p. 557), readily passes into a *γ-lactone dicarboxylic acid*; *ester,* b.p.$_{14}$ 149°, is formed by reduction of oxalosuccinic ester (A. **285,** 7).

a-Methyl Isocitric Acid, $CO_2H.C(CH_3)(OH).CH(CO_2H).CH_2CO_2H$, is formed rom acetosuccinic ester, hydrocyanic, and hydrochloric acids. When separated from its salts it immediately changes into *βγ-dicarboxy-γ-valerolactone,* which is also formed by oxidation of isopropyl succinic acid or pimelic acid, and from terebic acid by the oxidizing action of nitric acid. When heated it decomposes into H_2O, CO_2, and pyrocinchonic anhydride (B. **32**, 3861).

γ-Dimethyl Butyrolactone αβ-Dicarboxylic Ester, 
$$\begin{array}{ll} (CH_3)_2C\text{——} & CH.CO_2C_2H_5 \\ | & | \\ O.CO. & CH.CO_2C_2H_5 \end{array}$$
, m.p. 46°, b.p.$_{12}$ 174°, is prepared from β-methyl glycidic ester (p. 539) and sodium malonic ester. When boiled with hydrochloric acid, it yields terebic acid (p. 558) (C. 1906, II. 421).

αα-Dimethyl γ-Hydroxytricarballylic Lactone Acid (B. **30**, 1960), is formed from αα-dimethyl tricarballylic acid (see decomposition products of pinene (Vol. II.).

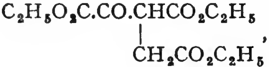
Cinchonic Acid, *Butenyl δ-Hydroxy-αβγ-tricarboxylic Lactone,* m.p. 168° (A. **234**, 85; B. **25**, R. 904), is produced when sodium amalgam acts on cinchomeronic acid or βγ-pyridine dicarboxylic acid. When heated to 168° it breaks down into CO_2 and pyrocinchonic anhydride (p. 518);


Cinchomeronic Acid. Cinchonic Acid. Pyrocinchonic Anhydride.

14. KETONETRICARBOXYLIC ACIDS

Carboxethyl Oxalacetic Ester, Oxalomalonic Ester, $C_2H_5O_2C.CO.CH(CO_2C_2H_5)_2$, b.p.$_{10}$ 220°, is obtained from sodium malonic ester and ethyl oxalyl chloride (C. 1898, I. 440). Nitrogen derivatives of carboxy-oxalacetic acid include *Dicyanomalonic Ester, β-cyano-γ-imido-isosuccinic ester,* $NC.C(NH)CH(CO_2C_2H_5)_2$, m.p. 93°, which is prepared from dicyanogen and malonic ester by means of sodium methoxide (p. 488). It can be hydrolyzed to *Dicyanomalonic Mono-ester,* m.p. 238°, and *Imido-oxalomalonic Mono-ester,* m.p. 134° with decomposition, is reduced by sodium amalgam to *α-Asparigine Carboxylic Acid,* $NH_2COCH(NH_2)CH(CO_2H)_2$, m.p. 120° with decomposition (A. **332**, 118. *α-Cyanoxalacetic Ester,* $C_2H_5O_2C.COCH(CN)CO_2C_2H_5$, m.p. 96°, is formed from oxalic mono-ester chloride and sodium cyanacetic ester. It is a strong acid (C. 1905, I. 1312).

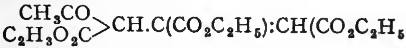
Acetone Tricarboxylic Ester, $C_2H_5O_2C.CH_2COCH(CO_2C_2H_5)_2$, is formed from malonic ester and sodium (p. 488). *Cyanacetone Dicarboxylic Ester,* $C_2H_5O_2C.-CH_2COCH(CN)CO_2C_2H_5$, m.p. 44°, is prepared from sodium acetone dicarboxylic ester and cyanogen chloride. Double decomposition of its *salts* with iodoalkyls produces O-alkyl ethers of the unsaturated enol form (C. 1901, I. 883). *αγ-Dicyanacetoacetic Ester,* $NC.CH_2CO.CH(CN)CO_2C_2H_5$, m.p. 88°, is prepared from chloracetyl cyanacetic ester (p. 607) and potassium cyanide (B. **41**, 2403).

Oxalosuccinic Ester, 
$$\begin{array}{l} C_2H_5O_2C.CO.CHCO_2C_2H_5 \\ \qquad\qquad\qquad\quad | \\ \qquad\qquad\qquad CH_2CO_2C_2H_5 \end{array}$$
, b.p.$_{17}$ 155°, is obtained from oxalic and succinic esters and sodium ethoxide. Heat at ordinary pressure decomposes it into CO and ethenyl tricarboxylic ester (p. 592) (B. **27**, 797). Since it is a β-ketonic acid its alcoholic solution becomes coloured red with ferric chloride and forms a pyrazolone derivative with phenylhydrazine (B. **27**, 797; A. 285, 1). The sodium salt of the ester reacts with iodo-alkyls, producing the O-ester of the enol modification. Hydrochloric acid decomposes it into CO_2 and α-ketoglutaric acid, $HO_2C.CH_2CH_2CO.CO_2H$ (comp. p. 568) (C. 1908, II. 768).

α-Acetotricarballylic Ester, $CH_3CO.CH(CO_2C_2H_5)CH(CO_2C_2H_5)CH_2(CO_2C_2H_5)$, b.p.$_9$ 175°, is formed from chlorosuccinic ester or fumaric ester and sodium acetoacetic ester (B. **23**, 3756; C. 1899, I. 180).

β-Acetotricarballylic Ester, $C_2H_5O_2CCH_2C(COCH_3)(CO_2C_2H_5)CH_2CO_2C_2H_5$, b.p.$_{18}$ 190°, is prepared from sodium acetosuccinic ester and chloracetic ester; also it results as a subsidiary product during the formation of acetosuccinic ester (A. **295**, 94). (See also α-Acetoglutaric Acid, p. 570.)

Olefine Ketotricarboxylic Acids.

a-Acetaconitic Ester,  $\begin{matrix}CH_3CO\\C_2H_3O_2C\end{matrix}>CH.C(CO_2C_2H_5):CH(CO_2C_2H_5)$, is formed by the reaction of chlorofumaric ester, chloromaleïc ester or acetylene dicarboxylic ester with sodium acetoacetic ester (C. 1900, II. 92).

15. TETRACARBOXYLIC ACIDS

A. PARAFFIN TETRACARBOXYLIC ACIDS

Formation.—(1) By the action of iodine on sodium malonic esters. (*2a*) From the sodium derivatives of malonic esters and alkylene dihalogenides or halogen malonic esters. (*2b*) From sodium tricarboxylic esters and halogen acetic esters. (3) By the addition of sodium malonic esters to the esters of unsaturated dicarboxylic acids, etc. Usually they are only known in the form of their esters.

sym.-**Ethane Tetracarboxylic Acid,** *Dimalonic Acid,* $(CO_2H)_2CH—CH(COOH)_2$, m.p. 168°, heated to higher temperatures becomes ethylene succinic acid. It is obtained from its ester by means of sodium hydroxide (B. **25**, 1158). The *ethyl ester,* m.p. 76°, b.p. 305° with decomposition, is produced by electrolysis (B. **28**, R. 450); by the action of chloromalonic ester and of iodine on sodium malonic ester; and by heating dioxalosuccinic ester (p. 656) Potassium hydroxide hydrolyses it to ethane tricarboxylic acid with the elimination of CO_2 (p. 592). See B. **28**, 1722, for the dihydrazide.

Sodium ethoxide converts ethane tetracarboxylic ester into a disodium derivative, which yields tetrahydronaphthalene tetracarboxylic ester (B. **17**, 449) with o-xylylene bromide, $C_6H_4(CH_2Br)_2$.

Ethyl Ethane Tetracarboxylic Ester, B. **17**, 2785.

Dimethyl Ethane Tetracarboxylic Ester, B. **18**, 1202; **28**, R. 451.

Diethyl Ethane Tetracarboxylic Ester, B. **21**, 2085; **28**, R. 452.

Alkylene Dimalonic Acids.—Methylene,- ethylene-, and trimethylene-dimalonic acids are, for practical reasons, included in this class. Their ethyl esters are produced when methylene iodide, ethylene bromide, and trimethylene bromide act on sodium malonic esters; also, by the action of aliphatic aldehydes on malonic ester in the presence of diethylamine, piperidine, and similar bases. In the latter case, the corresponding aldehyde amines are formed as intermediate compounds, such as *methanol piperidine,* $CH_2(OH)(NC_5H_{10})$, or *methylene bis-piperidine,* $CH_2(NC_5H_{10})_2$, which react with malonic ester to form alkylidene dimalonic esters.

Methylene Dimalonic Ester, Dicarboxyglutaric Ester, β-Propane Tetracarboxylic Ester, $CH_2[CH(CO_2C_2H_5)_2]_2$, b.p.$_{18}$ 205°; *dimethyl ester,* m.p. 48°, is formed (1) from formaldehyde or methylene iodide (B. **22**, 3294; **27**, 2345; **31**, 738, 2585), and malonic ester; also (2) by reduction of β-propylene tetracarboxylic ester (B. **23**, R. 240). Ammonia produces the *tetramide,* $CH_2[CH(CONH_2)_2]_2$, m.p. 249°, which, when heated above its melting point, passes into the *diimide,* $CH_2[CH(CO_2)NH]_2$ (J. pr. Ch. [2] **66**, 1). Sodium alcoholate and iodo-alkyls produce *methylene dialkyl malonic ester,* from which aa_1-dialkyl glutaric acids can be obtained by decomposition.

Ethylidene Dimalonic Ester, $CH_3.CH.[CH(CO_2C_2H_5)_2]_2$, is produced by the union of ethylidene malonic ester (p. 508) and sodium malonic ester.

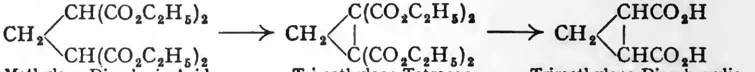
Ethylene Dimalonic Ester, Butane Tetracarboxylic Ester, $(CO_2C_2H_5)_2CH—CH_2.CH_2—CH(CO_2C_2H_5)_2$, is formed together with cyclopropane dicarboxylic ester when ethylene bromide acts on sodium malonic ester (B. **19**, 2038).

See, further, trimethylene 1,1-dicarboxylic acid and hexamethylene 1,1,4,4, tetracarboxylic ester (Vol. II.). Its di-sodium compound reacts with di-iodomethane to form cyclopentane-1,1,3,3,-tetracarboxylic ester (Vol. II.) (B. **31**, 1950).

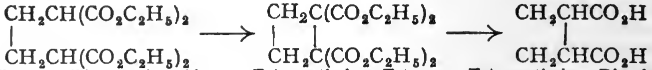
Alkyl Butane Tetracarboxylic Ester, B. **28**, R. 300, 464.

Trimethylene Dimalonic Ester, Pentane Tetracarboxylic Acid, $(CO_2C_2H_5)_2CH—CH_2.CH_2.CH_2—CH(CO_2C_2H_5)_2$, is formed, together with cyclobutane dicarboxylic ester (*q.v.*) in the action of trimethylene bromide on two molecules of sodium malonic ester. See also hexamethylene-1,1,3,3,-tetracarboxylic ester (Vol. II.).

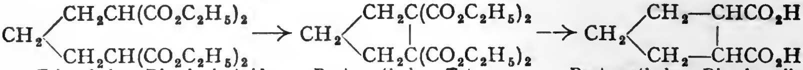
It is noteworthy that the disodium derivatives of the alkylene dimalonic esters are converted by the action of bromine or iodine, or of CH_2I_2 and $CH_2Br.CH_2Br$, into cycloparaffin tetracarboxylic esters. The alkylene dimalonic acids split off two CO_2-groups and yield alkylene diacetic acids; so, too, the cycloparaffin tetracarboxylic acids, obtained from the alkylene dimalonic acids, yield cycloparaffin dicarboxylic acids:



Methylene Dimalonic Acid. Trimethylene Tetracarboxvlic Acid. Trimethylene Dicarboxylic Acid.



Ethylene Diamalonic Acid. Tetramethylene Tetracarboxylic Acid. Tetramethylene Dicarboxylic Acid.



Trimethylene Diamlonic Acid. Pentamethylene Tetracarboxylic Acid. Pentamethylene Dicarboxylic Acid.

Propane αββγ-Tetracarboxylic Acid, Malonic Diacetic Acid, $(HO_2C)_2C(CH_2\text{-}CO_2H)_2$, m.p. 151° with decomposition into CO_2 and tricarballylic acid (p. 593); *ethyl ester*, b.p. 200, 295°, is prepared from sodium ethane tricarboxylic ester and chloracetic acid.

Tetracarboxylic acids are formed by the addition of sodium malonic and sodium alkyl malonic esters to the olefine dicarboxylic esters. These acids lose CO_2 and become tricarballylic acids (p. 593) (J. pr. Ch. [2] **35**, 349; B. **24**, 311; **24**, 2889; **26**, 364). If citraconic ester be added to sodium malonic ester and sodium alkyl malonic ester, a further partial condensation takes place of the first formed tetracarboxylic ester to *Ketocyclobutane Tricarboxylic Ester* (Vol. II.) (B. **33**, 3742):

Propane ααβγ-Tetracarboxylic Ester, $(CO_2C_2H_5)_2CH.CH(CO_2C_2H_5).CH_2\text{-}CO_2C_2H_5$, b.p. 203°, is obtained (1) from fumaric ester and sodium malonic ester (comp. ethylidene dimalonic ester); (2) from monochlorosuccinic ester and sodium malonic ester (B. **23**, 3756; **24**, 596). Tricarballylic acid is produced when the ester is hydrolyzed with alcoholic potassium hydroxide.

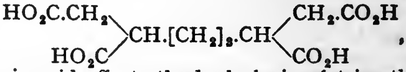
α-Ethyl Propane ααβγ-Tetracarboxylic Ester is formed from sodium ethyl malonic ester and fumaric ester. It yields a *sodium salt*, $(C_2H_5O_2C)_2C(C_2H_5).\text{-}CH(CO_2C_2H_5).CHNa(CO_2C_2H_5)$, which, with iodomethane, gives *α-ethyl γ-methyl propane ααβγ-tetracarboxylic ester* (comp. p. 593) (B. **33**, 3743).

αα-Dimethyl β-Cyanotricarballylic Ester, b.p.$_{25}$ 234°, is prepared from sodium cyanosuccinic ester (p. 592) and bromisobutyric ester (C. 1899, I. 826). Boiling dilute hydrochloric acid hydrolyzes it to αα-dimethyl tricarballylic acid (p. 594).

Butane αβγδ-Tetracarboxylic Acid, $CH_2(CO_2H)CH(CO_2H)CH(CO_2H)CH_2.\text{-}(CO_2H)$, m.p. 244°, is prepared from α-malonic tricarballylic acid. Its *dianhydride* m.p. 173° (B. **26**, 364; **28**, 882).

Methylene Disuccinic Acid, $CH_2[CH(CO_2H)CH_2(CO_2H)]_2$, m.p. 216° with decomposition (C. 1902, II. 733).

Trimethylene Disuccinic Acid,



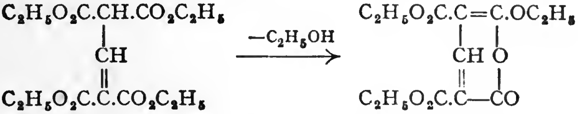
$$\begin{matrix}HO_2C.CH_2\\HO_2C\end{matrix}\!\!>CH.[CH_2]_3.CH<\!\!\begin{matrix}CH_2.CO_2H\\CO_2H\end{matrix}$$

, m.p. 159°, is produced when hydrochloric acid effects the hydrolysis of trimethylene dicyanosuccinic ester, the reaction product of trimethylene bromide and sodium cyanosuccinic ester (C. 1899, I. 326).

B. OLEFINE TETRACARBOXYLIC ACIDS

Ethylene Tetracarboxylic Ester, $(C_2H_5O_2C)_2C{=}C(CO_2C_2H_5)_2$, m.p. 58°, b.p. 325°, is formed from disodium malonic ester and iodine; from chloromalonic ester and sodium ethoxide (B. **29**, 1290); and from bromomalonic ester and K_2CO_3 or tertiary bases (B. **32**, 860; **34**, 2077).

Dicarboxyl Glutaconic Acid, Propylene ααγγ-Tetracarboxylic Ester, Methenyl Bismalonic Ester, $(C_2H_5O_2C)_2CH.CH{=}C(CO_2C_2H_5)_2$, is formed from sodium malonic ester and chloroform or carbon tetrachloride (B. **35**, 2881). It is an oil, which is converted by the action of piperidine in benzene solution into two *dimolecular modifications,* m.ps. 103° and 88°; these are transformed into the sodium salt of the ordinary ester by sodium alcoholate. The ester melting at 103° is hydrolyzed by hydrochloric acid into the bimeric glutaconic acid, m.p. 207° (p. 521), whilst the ordinary ester, similarly treated, yields the single glutaconic acid, m.p. 139° (B. **34**, 6757). Reduction with sodium amalgam produces the fluid dicarboxyl glutaric ester (p. 613). When heated it passes into the *δ-lactone,* m.p. 94°, by loss of alcohol (B. **22**, 1419; **26**, R. 9; A. **297**, 86).



$$\begin{array}{c} C_2H_5O_2C.CH.CO_2C_2H_5 \\ | \\ CH \\ \| \\ C_2H_5O_2C.C.CO_2C_2H_5 \end{array} \xrightarrow{-C_2H_5OH} \begin{array}{l} C_2H_5O_2C.C{=}C.OC_2H_5 \\ \quad\quad\quad\;\; |\quad | \\ \quad\quad\quad CH\;O \\ \quad\quad\quad\;\; \|\quad | \\ C_2H_5O_2C.C{-}CO \end{array}$$

Aqueous alkali hydroxide decomposes it into formic acid and malonic acid, together with glutaconic acid (p. 520) (B. **27**, 3061; C. 1897, I. 29, 229) (comp. also isoaconitic (p. 595). Ammonia, hydrazine, and hydroxylamine causes the splitting off of a malonic ester from the dicarboxyl glutaconic ester molecule, whereby a cyclic derivative of hydroxymethylene malonic ester is formed (p. 561). Aniline combines with it at 0° in ethereal solution to form *β-Anilino-dicarboxylglutaric Ester,* m.p. 46°, which, by further action of aniline, undergoes the decomposition described above (B. **30**, 1757, 2022). When sodium dicarboxyl glutaconic ester is heated with alcohol to 150°, *trimesic acid* (Vol. II.) is formed, a reaction which probably also depends on primary formation into hydroxymethylene malonic acid (C. 1901, II. 822).

αγ-Dicyanoglutuconic Ester, $\begin{smallmatrix} C_2H_5O_2C \\ NC \end{smallmatrix}{>}CH{-}CH{=}C{<}\begin{smallmatrix} CO_2C_2H_5 \\ CN \end{smallmatrix}$, m.p. 178°, and *αγ-Dicyanoglutaconic Amide* are formed from chloroform or carbon tetrachloride and sodium cyanoacetic ester or sodium cyanacetamide respectively (C. 1898, I. 29, 37; B. **26**, 2881).

Propylene αβγγ-Tetracarboxylic Acid. A derivative of this is *α-Cyanaconitic Ester,* $CNCH(CO_2C_2H_5)C(CO_2C_2H_5){:}CH(CO_2C_2H_5$, b.p.$_{25}$ 215°, which results from the reaction of cyanacetic ester, oxalacetic ester, and sodium alcoholate. The sodium salt of the ester and iodomethane give first *α-cyano-α-* or *-γ-methylaconitic ester,* b.p.$_{25}$ 211°, and then *α-cyano-αγ-dimethyl-aconitic ester,* $CNC(CH_3)(CO_2C_2H_5).C(CO_2C_2H_5){:}C(CH_3)CO_2C_2H_5$, b.p.$_{25}$ 206° (C. 1906, II. 21).

Butene Tetracarboxylic Ester, $CH_2(CO_2R)C(CO_2R)_2CH{:}CH(CO_2R)$, b.p.$_{14}$ 216–218°, is formed from sodium isaconitic ester and bromacetic ester (C. 1902, II. 722).

VII. THE PENTAHYDRIC ALCOHOLS OR PENTITOLS AND THEIR OXIDATION PRODUCTS

1. PENTAHYDRIC ALCOHOLS, PENTITOLS

One of these, *adonitol,* occurs in nature; all the rest have been obtained by the reduction of the corresponding aldopentoses with sodium amalgam. Their constitution follows from that of the aldopentoses from which they have been prepared (p. 616). The simplest pentitol, $C_5H_7(OH)_5$ or $CH_2.OH.\overset{*}{C}HOH.CHOH.\overset{*}{C}HOH.CH_2OH$, can have five theoretical modifications, because in the formula two asymmetric carbon atoms are present, and they are separated by a non-asymmetric carbon atom. There are two optically active modifications, one of which is known as l-arabitol. There is also an inactive resolvable modification, produced by the union of the preceding forms, and finally, there exist two optically inactive modifications due to internal compensation. These can not be resolved, and are known as *xylitol* and *adonitol.* The pentitols are oxidized to pentoses by bromine and sodium hydroxide (B. **27,** 2486). Comp. p. 640 for the stereochemical constitution of the pentitols.

The number of possible classes of pentahydric alcohols is 21; that of the classes of substances which can be termed oxidation products of the pentitols is 55, if the hydroxy-compounds are not divided into sub-classes according to the character of the alcoholic hydroxyls, otherwise the number rises to 231.

1. **l-Arabitol,** $C_5H_7(OH)_5$, m.p. 102°, is lævo-rotatory after the addition of borax to its aqueous solution. It is produced by the reduction of ordinary or l-arabinose (p. 618), and has a sweet taste (B. **24,** 538, 1839 note). *Benzal Arabitol,* m.p. 150° (B. **27,** 1535). *Diacetone Arabitol,* $b.p._{23}$ 145–152° (B. **28,** 2533). d-*Arabitol* is dextro-rotatory, and is produced by reduction of d-arabinose or d-lyxose. It combines with l-arabitol to form the racemic [d+l]-*Arabitol,* m.p. 106° (B. **32,** 555; **33,** 1802).

2. **Xylitol,** $C_5H_7(OH)_5$, is syrup-like and optically inactive. It results from the reduction of xylose (p. 619) B. **24,** 538; 1839 note; R. 567; **27,** 2487).

3. **Adonitol,** $C_5H_7(OH)_5$, m.p. 102°, is optically inactive. It occurs in *Adonis vernalis,* and is produced by the reduction of ribose (p. 619) (B. **26,** 633).

Adonitol Diformacetal, m.p. 145° (B. **27,** 1893).

Adonitol Diacetone, $b.p._{17}$ 150–155°.

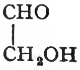
4. **Rhamnitol,** $CH_3.C_5H_6(OH)_5$, m.p. 121°, is dextro-rotatory; it results from the reduction of rhamnose (p. 619; B. **23,** 3103). *Dimethylene Rhamnitol,* $CH_3.C_5H_6O_4(CH_2)_2OH$, m.p. 138° (A. **299,** 321).

Aminotetroles: *Arabinamine,* $CH_2OH[CH(OH)]_3CH_2NH_2$, m.p. 99°, is lævo-rotatory, and is formed from l-arabinose oxime (p. 618) by reduction with sodium amalgam. It is a strong base, and is reduced by hydriodic acid to n-amylamine.

Xylamine is prepared from xylose oxime, and is a colourless syrup (p. 619), (C. 1904, I. 579).

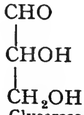
2. TETRAHYDROXYALDEHYDES, ALDOPENTOSES

The tetrahydroxyaldehydes, the first oxidation products of the pentahydric alcohols, are closely related to the pentahydroxyaldehydes or aldohexoses, the first class of the carbohydrates in the more restricted sense, to which also the aldopentoses are very similar in chemical behaviour. Whereas formerly the carbohydrates occupied a special position in the province of aliphatic chemistry, they are now found to be very closely allied to simpler classes of bodies. All aldehyde- and ketone-alcohols, which can be regarded as the first oxidation products of the simplest representatives of the polyhydric alcohols, contain, like the carbohydrates in a narrower sense, not only carbon, but also hydrogen and oxygen in the same proportion as exist in water, *e.g.:*



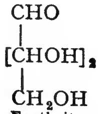
$$\begin{array}{c} CHO \\ | \\ CH_2OH \end{array}$$

Glycolyl Aldehyde (Diose, $C_2H_4O_2$)



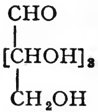
$$\begin{array}{c} CHO \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

Glycerose (Triose, $C_3H_6O_3$).



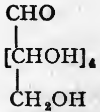
$$\begin{array}{c} CHO \\ | \\ [CHOH]_2 \\ | \\ CH_2OH \end{array}$$

Erythritos (Tetrose, $C_4H_8O_4$).



$$\begin{array}{c} CHO \\ | \\ [CHOH]_3 \\ | \\ CH_2OH \end{array}$$

Arabinose (Pentose, $C_5H_{10}O_5$).



$$\begin{array}{c} CHO \\ | \\ [CHOH]_4 \\ | \\ CH_2OH \end{array}$$

Dextrose (Hexose, $C_6H_{12}O_6$).

The simplest carbohydrates are, therefore, aldehyde-alcohols, such as those just mentioned, or ketone-alcohols—*e.g.*, fructose, $CH_2OH.CO.[CHOH]_3CH_2OH$ (p. 635).

The aldopentoses show the following reactions in common with the aldohexoses: 1. They form ethers with alcohols in the presence of small quantities of hydrochloric acid (B. **28**, 1156).

1*a*. They combine with the mercaptans to form mercaptals in the presence of hydrochloric acid (B. **29**, 547).

2*a*. They combine with aldehydes, especially with chloral and bromal.

2*b*. They unite with acetone in the presence of small quantities of hydrochloric acid.

3. They are reduced by sodium amalgam to alcohols: *pentitols.*

4. Nitric acid oxidizes them to hydroxycarboxylic acids: *tetrahydroxymono-* and *trihydroxydicarboxylic acids;* they reduce *Fehling's* solution.

5. They yield osamines with methyl alcoholic ammonia (B. **28**, 3082).

6. Hydrazine converts the pentoses into *aldazines* (B. **29**, 2308).

7. Phenylhydrazine changes them to hydrazones and characteristic dihydrazones: *osazones.*

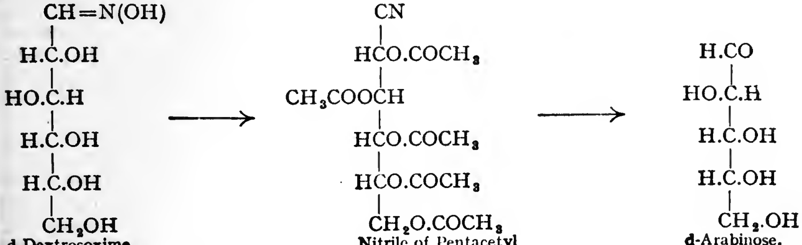
8. They yield oximes with hydroxylamine.

9. By successive treatment with hydrocyanic acid and hydrochloric acid they pass into pentahydroxyacids, the lactones of which may be reduced to hexoses (p. 630), whereby consequently the synthesis of a hexose from a corresponding pentose is realized.

However, the aldopentoses are (1) not fermented by yeast; (2) they yield furfuraldehyde or alkyl furfurals when they are distilled with hydrochloric acid or with dilute sulphuric acid. This reaction can be applied in the quantitative determination of the aldopentoses (B. **25**, 2912). (3) When they are heated with phloroglucinol and hydrochloric acid they give a cherry-red coloration (B. **29**, 1202).

Formation.—Their production from animal and vegetable sources will be indicated under the individual aldopentoses. However, a reaction will be given in this connection, which promises to afford a general method for the conversion of aldohexoses into aldopentoses.

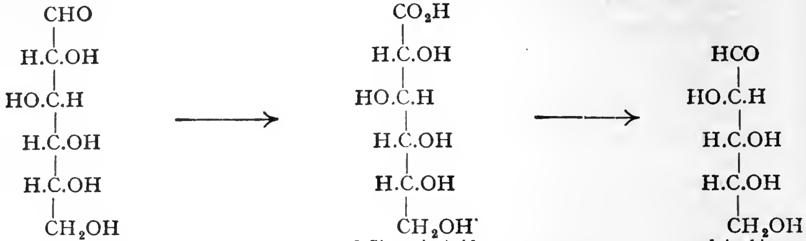
On treating d-dextrosoxime (p. 634) with acetic anhydride and sodium acetate, the nitrile of pentacetyl gluconic acid is obtained. This, when treated with ammoniacal silver solution gives up hydrocyanic acid, and is converted into d-arabinose diacetamide, which on hydrolysis with hydrochloric acid yields d-arabinose (B. **32**, 3666).



$$\begin{array}{c}\mathrm{CH{=}N(OH)}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array} \longrightarrow \begin{array}{c}\mathrm{CN}\\ |\\ \mathrm{HCO.COCH_3}\\ |\\ \mathrm{CH_3COOCH}\\ |\\ \mathrm{HCO.COCH_3}\\ |\\ \mathrm{HCO.COCH_3}\\ |\\ \mathrm{CH_2O.COCH_3}\end{array} \longrightarrow \begin{array}{c}\mathrm{H.CO}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2.OH}\end{array}$$

d-Dextrosoxime. **Nitrile of Pentacetyl Gluconic Acid.** **d-Arabinose.**

When d-dextrose is oxidized with chlorine water it is converted into d-gluconic acid which is further changed by hydrogen peroxide in presence of ferric acetate into d-arabinose (B. **32,** 3672):



d-Dextrose. d-Gluconic Acid. d-Arabinose.

d-Arabinose is the first aldopentose to be prepared synthetically, as it may be obtained from d-dextrose (p. 637) which can be synthesized.

The two degradation methods described above have led to the following reactions: the production of l- and d-xylose from l- and d-gulonic acid (see below, and p. 619); lyxose from galactose and galactonic acid (p. 619); l-erythritose and l-threose from l-arabinose and l-xylose (p. 597); d- and l-erythritose and l-threose from l- and d-arabonic acid and l-xylonic acid, etc.

The aldopentoses of the formula $CH_2OH.\overset{*}{C}HOH.\overset{*}{C}HOH.\overset{*}{C}HOH.CHO$, containing three asymmetric carbon atoms, can appear theoretically in eight optically active isomers, and four optically active, racemic (or [d+l] modifications which can be resolved (p. 639).

1. **Arabinose,** $C_4H_5OH)_4CHO$, is known in three modifications.

l-Arabinose, *Pectinose,* m.p. 160°, is formed when cherry gum and other gums (p. 663) are boiled with dilute sulphuric acid (B. **35,** 1457; **37,** 1210). Reduction produces l-arabitol (p. 616), and oxidation l-arabonic acid (p. 620) and l-trihydroxyglutaric acid, m.p. 127°; hydrochloric acid gives rise to furfural. It is *dextro-rotatory,* $[\alpha]_D=+105{\cdot}25^\circ$, and it reduces *Fehling's* solution. *Methyl l-Arabinose,* $C_5H_9O_5.CH_3$, m.p. 170° (B. **26,** 2407; **28,** 1156), is prepared from arabinose, methyl alcohol and hydrochloric acid. The action of iodomethane and silver oxide produces methylation of the OH-groups, forming *Trimethyl Methyl-Arabinose,* m.p. 44°, b.p.$_{14}$ 124°. Hydrochloric acid hydrolyzes this substance to *Trimethyl Arabinose,* $(CH_3O)_3C_5H_7O_2$, b.p.$_{19}$ 148–152° (C. 1906, II. 1045). l-*Arabinosazone,* $C_5H_8O_3(N_2HC_6H_5)_2$, m.p. 160° (B. **24,** 1840, footnote). *Arabinosone* (B. **24,** 1840, footnote; C. 1904, I. 579). l-*Arabinose* p-*Bromophenylhydrazone,* m.p. 150–155° (B. **27,** 2490). l-*Arabinose Semicarbazide,* m.p. 163° with decomposition (C. 1897, II. 894). l-*Arabinose Oxime,* m.p. 133° (B. **26,** 743) can be degraded to l-erythritose (p. 597), and reduced to l-arabinamine (p. 616). *Arabinose Ethyl Mercaptal,* m.p. 125°. *Arabinose Ethylene Mercaptal,* m.p. 154°. *Arabinose Trimethylene Mercaptal,* m.p. 150° (B. **29,** 547). *Arabinochloral,* α-form, m.p. 124°; β-form, m.p. 183°. *Arabinobromal,* $C_5H_8O_5.CH.CBr_3$, m.p. 210° (B. **29,** R. 544). *Arabinose Diacetone,* m.p. 42° (B. **28,** 1164). *Arabinose Tetranitrate,* m.p. 85° (B. **31,** 71). *Acetochlorarabinose,* $C_5H_6Cl(OCOCH_3)_3$, m.p. 149°, and *Acetobromarabinose,* $C_5H_6Br(OCOCH_3)_3$, m.p. 137°, are prepared from arabinose and acetyl chloride and bromide respectively. Silver acetate converts them into *Tetracetyl Arabinose,* $C_3H_6O(OCOCH_3)_4$, m.p. 80° (C. 1902, I. 911).

d-**Arabinose** is prepared (1) by degradation of d-dextrose oxime; from the reaction product it is best separated as the *diphenylhydrazone,* $C_4H_5(OH)_4$-$CH:NH(C_6H_5)_2$, which is decomposed by formaldehyde (C. 1902, I. 985); (2) by oxidation of d-gluconic acid by H_2O_2 (above), or by heating a solution of mercuric d-gluconate (C. 1908, I. 1166). It is *lævorotatory,* $[\alpha]_D=-105^\circ$. d-*Arabinosazone,* m.p. 160°. d-*Arabinose Diacetamide,* $C_5H_{10}O_4(NH.COCH_3)_2$, **m.p.** 187°.

[d+l]-**Arabinose**, m.p. 164°, is produced by the union of the two optically active forms of arabinose. It occurs in the urine of a sufferer from *pentosuria*. This is of interest, since, so far, only optically active sugars have been found to be produced as a result of metabolism. It can be resolved by asym.-d-amyl phenylhydrazone (B. **38**, 868). [d+l]-*Arabinosazone*, m.p. 167° (B. **33**, 2243).

2. l-**Xylose**, *Wood Sugar*, $C_4H_5(OH)_4.CHO$, m.p. 143°, is produced when wood gums (B. **22**, 1047; **23**, R. 15; C. 1902, I. 301), corn-cobs (B. **24**, 1657), maize, or elder pith (B. **35**, 1457) are boiled with dilute acids; by the degradation of l-gulonic acid (p. 649) by hydrogen peroxide (B. **33**, 2142); also, by pancreatic hydrolysis of nucleo-proteins (B. **35**, 1467). It is *dextro-rotatory*, and yields inactive xylitol (p. 616) on reduction; oxidation converts it into l-xylonic acid (p. 620) and inactive trihydroxyglutaric acid, m.p. 152°. Hydrocyanic acid produces l-gulonic acid and l-idonic acid (p. 650). l-*Xylosazone*, m.p. 160°.

d-**Xylose** is obtained from d-gulonic lactone by degradation. It is *lævorotatory* (B. **33**, 2145). (d+l)-*Xylosazone*, m.p. 210–215°, with decomposition (B. **27**, 2488; **33**, 2145). *Methyl Xylose*, $C_5H_9O_5.CH_3$, α-, m.p. 91°; β-, m.p. 156° (B. **28**, 1157). *Xylochloral*, m.p. 132° (B. **28**, R. 148).

3. **Lyxose**, m.p. 101°, is prepared by reduction of lyxonic lactone (p. 620); from pentacetyl galactonic nitrile by loss of hydrocyanic acid (B. **30**, 3103); and from d-galactonic acid and H_2O_2 (B. **33**, 1798). Addition of hydrocyanic acid and hydrolysis produces galactonic and talonic acids (B. **33**, 2146).

4. **Ribose**, $C_4H_5(OH)_4CHO$, is produced by oxidation of l-arabinose to l-arabonic acid, conversion of this l-arabonic acid (p. 620) and reduction of the lactone of this acid (B. **24**, 4220).

5. **Apiose**, *β-Hydroxymethyl Erythritose*, $(CH_2OH)_2C(OH)CH(OH)CHO$, is prepared by hydrolysis of *apiine*, a glucoside occurring in parsley (Vol. II.). It differs from the isomeric pentoses by reason of its branched carbon chain. Oxidation with bromine water produces tetrahydroxyisovaleric acid (A. **321**, 71).

6. **Rhamnose**, or **Isodulcitol**, $CH_3(CHOH)_4CHO+H_2O$, m.p. 93°, in anhydrous form; b.p. 122–126° when crystallized from acetone. It is dextrorotatory (B. **29**, R. 117, 340). It results upon decomposing different glucosides (quercitrine, xanthorhamnine, rhamninose, a disaccharide, derived from galactose and rhamnose (C. 1900, **1**, 251), hesperidine, naringine) with dilute sulphuric acid. Isodulcitol yields α-methyl furfural when distilled with sulphuric acid (B. **22**, R. 751).

It gives rise to rhamnitol upon reduction, and by oxidation l-trihydroxyglutaric acid (m.p. 127°). HNC and hydrochloric acid convert it into rhamnose carboxylic acid (p. 650; B. **22**, 1702); *oxime* has been decomposed into methyl tetrose (p. 597; B. **29**, 1378); *hydrazone*, m.p. 159°, and its *osazone*, m.p. 180° (B. **20**, 2574). *Acetone Rhamnose*, $C_6H_{10}O_5:C_3H_6$, m.p. 90° (B. **28**, 1162). *Rhamnose Ethyl Mercaptal*, m.p. 136°. *Ethylene Mercaptal*, m.p. 169° (B. **29**, 547). *Tetranitrate*, m.p. 135° (B. **31**, 71).

7. **Isorhamnose** has been obtained by the reduction of the lactone of isorhamnonic acid.

8. **Chinovose**, $CH_3[CHOH]_4CHO$, isomeric with rhamnose, is a product obtained by decomposing chinovine, occurring in varieties of quina and cinchona with hydrochloric acid. *Osazone*, m.p. 193–194° (B. **26**, 2417).

9. **Rhodeose**, $CH_3[CH(OH)]_4CHO$, is one of the methyl pentoses obtained by decomposing the pentosides *convovulin* and *jalapin* (Vol. II.). It is strongly dextro-rotatory, and is the optical antipodes to *Fucose*. This substance is obtained by hydrolysis of the *Fucus* variety of sea-weeds with dilute sulphuric acid. *Osazone*, m.p. 177°. Determination of configuration (B. **40**, 2434).

3. TETRAHYDROXYMONOCARBOXYLIC ACIDS

Acids of this class are obtained by oxidizing the aldopentoses with bromine water or dilute nitric acid. They readily pass into lactones, some of which yield pentoses on reduction. Furthermore, oxidation changes them in part to dicarboxylic acids. Hydriodic acid reduces some of them to lactones of the monohydroxyparaffin carboxylic acids. All the known acids are optically active.

Tetrahydroxy-n-*valeric acids*, have theoretically eight optically active forms, as have the *aldopentoses with an equal number of carbon atoms*, five of which **are known**, and four are [d+l] modifications.

(1) **l-Arabonic Acid,** $CO_2H[CHOH]_3CH_2OH$, $[a]_D^{20} = -73.9°$, is prepared from l-arabinose (B. **21,** 3007). It readily yields a *lactone,* $C_5H_8O_5$, m.p. 95–98°, and is converted by oxidation into l-*trihydroxyglutaric acid*; *phenylhydrazide,* m.p. 215° (B. **23,** 2627; **24,** 4219). *Tetracetyl* l-*Arabonic Nitrile,* m.p. 117°, is produced from l-arabinose oxime, acetic anhydride, and sodium acetate. Silver oxide changes it into triacetyl l-eythrose (B. **32,** 3666). d-*Arabonic Acid,* $[a]_D^{20} = +73.7°$, is formed from d-arabinose and bromine water; *lactone,* m.p. 98°. Oxidation by H_2O_2 converts it into d-erythritose, [d+l]-*Arabonic Lactone,* m.p. 116° (B. **32,** 556). When heated to 145° with aqueous pyridine it gives l-arabonic and pyromucic acid, together with some

(2) l-**Ribonic Acid,** which, under the same conditions, is partially reconverted into arabonic acid. *Ribonic Lactone,* $C_3H_8O_5$, m.p. 72–76° (B. **24,** 4217); *phenylhydrazide,* m.p. 163°.

(3) l-**Xylonic Acid** is prepared from l-xylose and bromine. It yields a sparingly soluble bromocadmium double salt (comp. B. **35,** 1473). Pyridine converts it into

(4) d-**Lyxonic Acid**; *lactone,* m.p. 113° (B. **30,** 3107) (see also Lyxose, p. 619); *phenylhydrazide,* m.p. 162°.

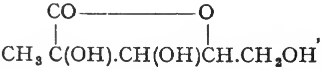
(5) **Apionic Acid,** *Tetrahydroxyisovaleric Acid,* $(CH_2OH)_2C(OH)CH(OH)\text{-}COOH$, is produced from apiose (p. 619) and bromine water. *Phenylhydrazide,* m.p. 127°, is converted by hydriodic acid and phosphorus into isovaleric acid (A. **321,** 78).

(6) **Rhamnonic Acid** is formed from rhamnose and bromine, and passes directly into the *lactone,* $C_6H_{10}O_5$, m.p. 150° (B. **23,** 2992; A. **271,** 73). *Methyl Rhamnonic Lactone,* $C_6H_8(CH_2)O_5$, m.p. 179° (A. **309,** 323). When heated with pyridine to 150° it yields some

(7) **Isorhamnonic Acid,** of which the *lactone,* m.p. 151°, when oxidized yields xylotrihydroxyglutaric acid (p. 621) (B. **29,** 1961) (see also Isorhamnose, p. 619).

(8) **Saccharic Acids** is the name given to a number of *tetrahydroxypentane carboxylic acids* which are obtained from the *hexoses* or disaccharides by the action of alkalis, or, better, lime-water, accompanied by *atomic migration.* They readily pass into *lactones,* known as *saccharines,* which must not be confused with saccharine (Vol. II.) a sweetening agent entirely unconnected with sugars and their associated compounds.

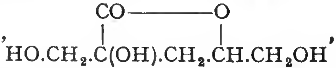
Saccharine,



$$\begin{array}{l}CO\text{———————}O\\ CH_3\,C(OH).CH(OH)CH.CH_2OH\end{array}$$

, m.p. 160°, possesses a bitter taste.

Isosaccharine,



$$\begin{array}{l}CO\text{—————}O\\ HO.CH_2.C(OH).CH_2.CH.CH_2OH\end{array}$$

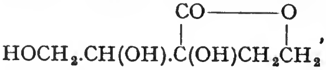
, m.p. 95°.

Metasaccharine,

$$\begin{array}{l}CO\text{———}O\\ HOCH.CH_2.CH.CH(OH)CH_2OH\end{array}$$

, m.p. 141°.

Parasaccharine,



$$\begin{array}{l}CO\text{————}O\\ HOCH_2.CH(OH).C(OH)CH_2CH_2\end{array}$$

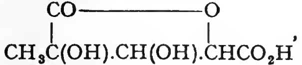
, a syrup.

Saccharine is produced by the action of lime-water on dextrose, lævulose and invert sugar; iso-, meta-, and para-saccharine from lactose or galactose and lime-water. When reduced with hydriodic acid, saccharine and isosaccharine yield *aγ-dimethyl butyrolactone,* whilst metasaccharine gives γ-n.-caprolactone. Nitric acid converts saccharine into a-methyl trihydroxyglutaric acid (*saccharonic acid*); isosaccharine into aγ-dihydroxyglutaric γ-carboxylic acid, $(HO_2C)_2C(OH)\text{-}CH_2CH(OH)CO_2H$; metasaccharine into aβδ-trihydroxyadipic acid (see below); and parasaccharine to parasaccharonic acid and hydroxycitric acid (p. 622). H_2O_2 (p. 618) brings about the degradation of iso- and para-saccharine to two *ketopentane trioles,* $HOCH_2.COCH_2CH(OH)CH_2OH$, and $HOCH_2.CH(OH).CO.\text{-}CH_2CH_2OH$, respectively; metasaccharine gives an *aldotriose metasaccharopentose,* $HOC.CH_2CH(OH)CH(OH)CH_2OH$, the aldehyde of a βγδ-trihydroxyvaleric acid, which is reduced by hydriodic acid to γ-valerolactone (A. **218,** 373; **299,** 323; B. **18,** 631, 2514; **35,** 2361; **37,** 3612; **38,** 2671; **41,** 158).

4. TRIHYDROXYDICARBOXYLIC ACIDS

Trihydroxy-n.-glutaric Acids, $CO_2H[CHOH]_3CO_2H$, can theoretically exist in four stereochemical modifications, corresponding with the four pentitols (p. 615), and in addition in an inactive form, which can be resolved.

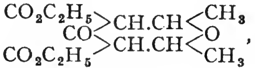
d-*Trihydroxyglutaric Acid,* m.p. 127°, is prepared from d-arabinose and nitric acid. l-*Trihydroxyglutaric Acid,* m.p. 127°, is formed from l-arabinose and nitric acid, as well as by the oxidation of rhamnose (p. 619) and sorbinose (p. 636) (B. **21**, 3276). [d+l]-*Trihydroxyglutaric Acid,* m.p. 154°, results from the union of d- and l-trihydroxyglutaric acid in acetone solution (B. **32**, 558). i-*Xylotrihydroxyglutaric Acid,* m.p. 152°, is formed when xylose is oxidized; it corresponds with xylitol (p. 616). It is very similar to, but not identical with, the racemic acid (B. **32**, 559). i-*Ribotrihydroxyglutaric acid* results from the oxidation of ribose, and corresponds with adonitol (p. 616). It readily passes into a *lactonic acid,* $C_3H_6O_6$, m.p. 170° (B. **24**, 4222).

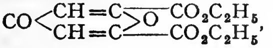
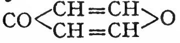
Saccharonic Acid, *α-Methyl Trihydroxyglutaric Acid,* $CH_3C(OH)(CO_2H)CH(OH)CH(OH)(CO_2H)$, is formed by the oxidation of saccharine (see above) with nitric acid. It changes in a desiccator, or when heated, into a lævo-rotatory lactone, *Saccharone,*  $\begin{array}{l}CO\text{————}O\\ \quad |\qquad\qquad\qquad |\\ CH_3C(OH).CH(OH).CHCO_2H\end{array}$, m.p. 145–156° (A. **218**, 363).

Hydriodic acid converts the lactone into α-methyl glutaric acid (p. 502).

Trihydroxyadipic Acid, $CO_2HCH(OH)CH_2CH(OH)CH(OH)CO_2H$, m.p. 146° with decomposition, results from the oxidation of metasaccharine (see above) with dilute HNO_3 (B. **18**, 1555; **37**, 2668). Heated with HI it is reduced to adipic acid.

5. **DIHYDROXYKETONE DICARBOXYLIC ACIDS:** The pyrone dicarboxylic esters, resulting from the condensation of acetone dicarboxylic esters with aldehydes, are anhydrides (like ethylene oxide) of the dihydroxyketone dicarboxylic acids.

Dimethyl Tetrahydropyrone Dicarboxylic Ester,  $\begin{array}{rl}CO_2C_2H_5> & CH.CH<CH_3\\ CO & \qquad\quad O\\ CO_2C_2H_5> & CH.CH<CH_3\end{array}$, m.p. 102°, is formed from acetone dicarboxylic ester, acetaldehyde, and hydrochloric acid (B. **29**, 994).

6. **TRIKETONE DICARBOXYLIC ACIDS.** *Acetone Dioxalic Ester, Diethyl Xanthochelidonic Ester,* $CO[CH_2CO.CO_2C_2H_5]_2$, m.p. 104°, is obtained from acetone, oxalic ester, and sodium ethoxide. Hydrochloric acid converts it into *Chelidonic Ester,*  $CO<\begin{array}{l}CH=C—CO_2C_2H_5\\ \qquad\;\; >O\\ CH=C—CO_2C_2H_5\end{array}$, m.p. 63°. Some other acids, allied with this, are also derived from *pyrone,*  $CO<\begin{array}{l}CH=CH\\ CH=CH\end{array}>O$ (Vol. II.), such as a product of dehydration of *carbonyl diacetoacetic ester,* $CO[CH(COCH_3)CO_2C_2H_5]_2$, prepared from copper acetoacetic ester and phosgene (B. **19**, 19).

7. DIHYDROXYTRICARBOXYLIC ACIDS

Desoxalic Acid, $CO_2H.CHOH.C(OH)(CO_2H)_2$, is a deliquescent crystalline mass; *triethyl ester,* $CO_2C_2H_5.CHOH.C(OH).(CO_2C_2H_5)_2$, m.p. 78°, b.p.$_2$ 156°, results from the action of sodium amalgam on diethyl oxalate (A. **297**, 96). When its aqueous solution is evaporated, or when its ester is heated with water or dilute acids to 100°, the acid yields carbon dioxide and racemic acid (p. 601):

$$\underset{\text{Desoxalic Acid.}}{HO_2C.CH(OH)C(OH)CO_2H)_2} \longrightarrow \underset{\text{Racemic Acid.}}{HO_2C.CH(OH)CH(OH)CO_2H} + CO_2.$$

Acid radicals can be substituted for the two hydroxyl groups of the desoxalic ester. Heated with hydriodic acid, desoxalic acid gives off carbon dioxide, and is reduced to succinic acid.

Desoxalic ester and phenylhydrazine yield phenylhydrazine glyoxylic ester, whilst isonitrosomalonic ester and glycollic acid are the products of reaction with hydxroylamine (B. **29**, R. 908.

Hydroxycitric Acid, *αβ-Hydroxy-tricarballylic Acid,* $CO_2HCH_2C(OH)(CO_2H)$-$CH(OH)CO_2H$, m.p. 160°, accompanies aconitic, tricarballylic, and citric acids in beet juice, and is produced by boiling chlorocitric acid (from aconitic acid and HClO) with alkalis or water (B. **16**, 1078). It can be obtained pure by oxidation of parasaccharine (p. 620) with nitric acid (B. **37**, 3614).

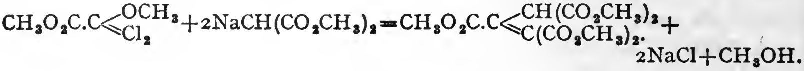
αγ-Dihydroxypropane ααγ-Tricarboxylic Acid, αγ-Dihydroxyglutaric γ-Carboxylic Acid, $(CO_2H)_2C(OH)CH_2CH(OH)COOH$, results from the oxidation of isosaccharine with nitric acid. It is a thick crystalline mass. At 100° it loses carbon dioxide, and forms αγ-dihydroxyglutaric acid. Hydriodic acid and phosphorus convert it into glutaric acid, $C_3H_6(CO_2H)_2$ (B. **38**, 2671).

8. PENTACARBOXYLIC ACIDS

Paraffin Pentacarboxylic Acids. *Propane αββγγ-Pentacarboxylic Acid, βγ-Dicarboxytricarballylic Acid,* $(CO_2H)_2CH.C(CO_2H)_2.CH_2CO_2H$, m.p. 150°, is obtained from its *penta-ethyl ester,* the reaction product of sodium malonic ester and chlorethane tricarboxylic ester (p. 592). *Propane ααβγγ-Pentacarboxylic Methyl Ester, αγ-Dicarboxytricarballylic Ester,* $CH_3O_2C.CH[CH(CO_2CH_3)_2]_2$, m.p. 86°, is prepared from dichloracetic ester and two molecules of sodium malonic ester; also, by reduction of dicarboxyaconitic ester (see below) with zinc and glacial acetic acid (A. **347**, 5). Similarly, reduction of dicarboxy-methyl-aconitic ester gives rise to *Butane ααβγγ-Pentacarboxylic Methyl Ester, αγ-Dicarboxy-α-methyl-tricarballylic Ester,* $(CH_3O_2C)_2.CH.CH(CO_2CH_3).C(CH_3)(.CO_2CH_3)_2$, m.p. 59°. These esters yield tricarballylic or the stereoisomeric α-methyl tricarballylic acids on hydrolysis and expulsion of CO_2.

Butane αββγδ-Pentacarboxylic Ester, $C_2H_5O_2C.CH_2CH(CO_2C_2H_5)C(CO_2$-$C_2H_5)_2.CH_2CO_2C_2H_5$, b.p.$_{16}$ 217°, is formed from chlorosuccinic ester and sodium ethenyl tricarboxylic ester.

Olefine Pentacarboxylic Acids: *Dicarboxyaconitic Pentamethyl Ester,* $(CH_3O_2C)_2.C:C(CO_2CH_3).CH(CO_2CH_3)_2$, m.p. 62°, is formed by condensation of dichloroxalic methyl ester and two molecules of sodium malonic methyl ester, instead of the expected dicarboxy-methyl-citric ester, which loses methyl alcohol:



$$CH_3O_2C.C{<}^{OCH_3}_{Cl_2}+2NaCH(CO_2CH_3)_2=CH_3O_2C.C{<}^{CH(CO_2CH_3)_2}_{C(CO_2CH_3)_2.}+2NaCl+CH_3OH.$$

The ester, when hydrolyzed, loses CO_2 and yields aconitic acid; with sodium and iodomethane it forms *α-Methyl Dicarboxyaconitic Ester, Butylene ααβγγ-Pentacarboxylic Ester,* $CH_3C(CO_2CH_3)_2C(CO_2CH_3):C(CO_2CH_3)_2$, m.p. 86° A. **347**, 1).

Butylene αβγγδ-Pentacarboxylic Ester, $C_2H_5O_2C.CH_2.C(CO_2C_2H_5)_2C(CO_2C_2$-$H_5):CHCO_2C_2H_5$, b.p.$_{10}$ 230°, is prepared from sodium ethenyl tricarboxylic ester and chlorofumaric ester (B. **31**, 47). *Butylene ααγγδ-Pentacarboxylic Ester,* $C_2H_5O_2C.CH_2C(CO_2C_2H_5)_2CH:C(CO_2C_2H_5)_2$, b.p.$_{12}$ 224°, is formed from sodium dicarboxyglutaconic ester (p. 615) and chloracetic ester (J. pr. Ch. [2] **66**, 1, 104).

VIII. HEXA- AND POLY-HYDRIC ALCOHOLS, AND THEIR OXIDATION PRODUCTS

1 A. HEXAHYDRIC ALCOHOLS, HEXAHYDROXYPARAFFINS, HEXITOLS

The hexahydric alcohols approach the first class of sugars (p. 625)—the dextroses—very closely. They resemble them in properties; they have a very sweet taste, but they do not reduce an alkaline copper solution, and are not fermented by yeast. δ-Mannitol, δ-sorbitol, and dulcitol occur in nature. These three and certain hexitols have been prepared by the reduction of the corresponding dextroses—aldo- and keto-hexoses—with sodium amalgam. Moderate oxidation converts them into dextroses. The compounds which the hexitols yield with aldehydes, especially formaldehyde and benzaldehyde, in the presence of hydrochloric acid or sulphuric acid, or with acetone and hydrochloric acid, are characteristic of them (A. **299,** 316; B. **27,** 1531; **28,** 2531).

Theory requires the existence of 28 classes of hexahydroxy-paraffin alcohols, which give rise to 79 classes of oxidation products, if the hydroxy compounds are included with those of the glycol oxidation products. The total number of sub-classes of oxidation compounds amounts to 434, of which 28 are free from alcoholic hydroxyls.

The simplest hexitols with six carbon atoms contain four asymmetric carbon atoms in the molecule. According to the theory of *van 't Hoff* and *Le Bel,* 10 *simple* spacial isomeric forms are possible for such a compound.

1. **Mannitol** or **Mannite,** $CH_2OH[CHOH]_4CH_2OH$, exists in three modifications: dextro-, lævo-, and inactive mannitol; the latter is identical with the *a-acritol* made from synthetic *a-acrose* or [d+l] *fructose.* It is the parent substance for the synthesis of numerous derivatives of the mannitol series (B. **23,** 373), and also of *dextrose* (p. 632) and of *lævulose* (p. 635), as will be more fully explained under these bodies.

Ordinary, or **d-Mannitol,** m.p. 166°, occurs frequently in plants and in the manna-ash (*Fraxinus ornus*), the dried sap of which is *manna.* It is obtained from the latter by extraction with alcohol and allowing the solution to crystallize. It is produced in the ropy fermentation of the different varieties of sugar, and may be artificially prepared, together with sorbitol, by the action of sodium amalgam on d-mannose (p. 631), d-fructose (B. **17,** 127; **23,** 3684).

Mannitol crystallizes from alcohol in delicate needles, and from water in large rhombic prisms. It possesses a very sweet taste. Its solution is dextro-rotatory in the presence of borax. When oxidized with care, it yields fructose (previously known as mannitose) (B. **20,** 831), and d-mannose (B. **21,** 1805). Nitric acid oxidizes mannitol to d-mannosaccharic acid (B. **24,** R. 763) (p. 653), erythritic acid, and oxalic acid. Hydriodic acid converts it into 2- and 3-hexyl iodide (B. **40,** 140).

When mannitol is heated to 200° it loses water and forms the anhydrides, *Mannitan,* $C_6H_{12}O_5$, and *Mannide,* $C_6H_{10}O_4$, m.p. 87°, b.p.$_{30}$ 176°. The latter is also obtained by distilling mannitol in a vacuum.

Esters.—*Mannitol Dichlorhydrin,* $C_6H_8Cl_2(OH)_4$, m.p. 174°, is formed when *d*-mannitol is heated with concentrated hydrochloric acid. Hydrobromic acid yields the *dibromhydrin,* m.p. 178°.

Nitromannitol, $C_6H_8(O.NO_2)_6$, m.p. 113°, is obtained by dissolving mannitol in a mixture of concentrated nitric and sulphuric acids. It crystallizes from alcohol and ether in bright needles; it melts when carefully heated and deflagrates strongly. When struck it explodes very violently. Alkalis and ammonium sulphide regenerate mannitol. Ammonia, or, better, pyridine, acting on hexanitromannitol, produces *pentanitromannitol,* m.p. 82° (C. 1901, II. 983; B. **36,** 794).

Hexacetyl d-Mannitol, $C_6H_6(OCOCH_3)_6$, m.p. 119° (B. **12**, 2059), when left in contact with liquid HCl, changes into *Tetra-acetyl Mannitol Dichlorhydrin*, $C_6H_8(C_2H_3O_2)_4Cl_2$, m.p. 214° (B. **35**, 842).

Hexabenzoyl Mannitol, m.p. 149°.

Mannitol Triformal, $C_6H_8O_6(CH_2)_3$, m.p. 227° (A. **289**, 20).

Mannitol Tribenzal, $C_6H_8O_6(CHC_6H_5)_3$, m.p. 213–217° (B. **28**, 1979).

Mannitol Triacetone, $C_6H_8O_6(C_3H_6)_3$, m.p. 69°, is obtained from mannitol, acetone, and a little hydrochloric acid. It has a bitter taste (B. **28**, 1168).

Lævo-mannitol, m.p. 163–164°, is obtained by the reduction of l-mannose (from l-arabinose carboxylic acid, p. 649) in weak alkaline solution with sodium amalgam (B. **23**, 375). It is quite similar to ordinary mannitol, but melts a little lower, and in the presence of borax is lævorotatory.

Inactive Mannitol, [d+l] *Mannitol*, m.p. 168°, is produced in a similar manner, from inactive mannose (from [d+l]-mannonic acid). It is identical with the synthetically prepared *α-acritol* (from *α-acrose*, p. 636) (B. **23**, 383). It resembles ordinary mannitol, but in aqueous solution is inactive even in the presence of borax. Nitric acid oxidizes it to inactive mannose and inactive mannonic acid. The latter can be resolved into d- and l-mannonic acids (B. **23**, 392). d- and l-Mannonolactones may be reduced to d- and l-mannoses, and these to d- and l-mannitols. All of these compounds have been synthesized in this way.

2. d- and l-**Iditols** are colourless syrups formed by the reduction of d- and l-iodoses; *tribenzal* compounds, m.p. 219–223° (B. **28**, 1979).

3. d-**Sorbitol** (p. 642), $CH_2OH(CHOH)_4CH_2OH$, m.p. 75° (anhydrous, 104–109°), occurs in mountain-ash berries, forming small crystals which dissolve readily in water. It is produced in the reduction of d-dextrose, and together with d-mannitol in the reduction of d-fructose (p. 637) (B. **23**, 2623). It is reduced to secondary hexyl iodide (B. **22**, 1048) when heated with hydriodic acid.

Sorbitol Triformal, $C_6H_8O_6(CH_2)_3$, m.p. 206° (A. **289**, 23).

Triacetone Sorbitol, $C_6H_8O_6(C_3H_6)_3$, m.p. 45°, b.p.$_{25}$ 172°.

l-**Sorbitol** (p. 642), m.p. 75°, is obtained by the reduction of l-gulose (p. 634) (B. **24**, 2144).

4. **Dulcitol**, *Melampyrin*, $CH_2OH(CHOH)_4CH_2OH$ (p. 642), m.p. 188°, occurs in various plants, and is obtained from dulcitol manna (originating in Madagascar). It is produced artificially by the action of sodium amalgam on lactose and d-galactose. It crystallizes in large monoclinic prisms, having a sweet taste. It dissolves in water with more difficulty than mannitol, and is almost insoluble even in boiling water. Its solution remains optically inactive even in the presence of borax (B. **25**, 2564). Hydriodic acid converts it into the same hexyl iodide that mannitol yields. Nitric acid oxidizes dulcitol to mucic acid. There is also an intermediate aldehyde compound that combines with two molecules of phenylhydrazine and forms the *osazone*, $C_6H_{10}O_4(N_2H.C_6H_5)_2$ (B. **20**, 1091).

Hexacetyl Dulcitol, m.p. 171°.

Dimethylene Dulcitol, $C_6H_{10}O_6(CH_2)_2$, m.p. 244° (A. **299**, 318). *Dibenzal Dulcitol*, $C_6H_{10}O_6(CHC_6H_5)_2$, m.p. 215–220° (B. **27**, 1554). *Diacetone Dulcitol*, $C_6H_{10}O_6(C_3H_6)_2$, m.p. 98°, b.p.$_{18}$ 194° (B. **28**, 2533). *Dulcitol Hexanitrate*, m.p. about 95°. *Dulcitol Pentanitrate*, m.p. about 75° (B. **36**, 799).

5. d-**Talitol**, m.p. 86°, is produced in the reduction of α-talose.

Tribenzal d-*Talitol*, m.p. 206° (B. **27**, 1527; C. 1908, I. 1529).

[d+l] **Talitol**, m.p. 66°, is formed by the reduction of the body produced when dulcitol is oxidized with PbO_2 and hydrochloric acid (B. **27**, 1530).

6. **Rhamnohexitol**, $CH_3.[CHOH]_5.CH_2OH$, m.p. 173°, is formed when rhamnohexose (p. 635) is reduced with sodium amalgam (B. **23**, 3106).

7. **Glucamines.** These bodies stand in the same relation to the hexose imines and amines (p. 636) as the hexitols to the hexoses. They are formed (1) from the hexose oximes, and (2) the hexose amines by reduction with sodium amalgam. d-*Glucamine*, $CH_2OH.[CHOH]_4CHNH_2$, m.p. 128°, is prepared from dextrose oxime and also from isodextrosamine (p. 636). It is a strong base, and is dextro-rotatory. Together with the above are formed d-*Manno-amine*, m.p. 139°, d-*Galactamine*, m.p. 139°, is lævorotatory (C. 1902, II. 1356; 1903, II. 1237; 1904, I. 871).

1 B. **HEPTAHYDRIC ALCOHOLS: Perseïtol** or **Mannoheptitol**, $C_7H_9(OH)_7$, is known in three modifications: d-mannoheptitol, m.p. 187°, l-mannoheptitol,

m.p. 187°, and [d+l] *mannoheptitol*, m.p. 203°. The d-mannoheptitol or perseïtol occurs in *Laurus persea*, and is obtained, like the other two modifications, by the reduction of the corresponding mannoheptoses (B. **23**, 936, 2231). The [d+l] mannoheptitol is formed when equal quantities of d- and l-mannoheptitol are mixed (A. **272**, 189). Hydriodic acid reduces it to hexahydrotoluene (B. **25**, R. 503).

α-Glucoheptitol, $CH_2OH(CHOH)_5CH_2OH$, m.p. 128°, is obtained from α-glucoheptose (p. 637; A. **270**, 81). *Triacetone α-Glucoheptitol*, $C_2H_{10}O_7(C_3H_6)_3$, b.p.$_{24}$ 200° (B. **28**, 2534).

α-Galaheptitol, $C_7H_{16}O_2$, m.p. 183°, is obtained from α-galaheptose (p. 637).

Volemitol, $C_7H_9(OH)_7$, m.p. 156°, dextrorotatory, is found in the pileated mushroom, *Lactarius volemus* (B. **28**, 1973) and in the *Primulaceæ* (C. 1902, II. 1513).

Anhydro-enneaheptitol, $C_9H_{18}O_8$, m.p. 156°, is formed from acetone and formaldehyde with lime and water. It is an anhydride of the heptahydric alcohol $[CH_2OH]_3 : C.CH(OH)C : [CH_2OH]_2$ (B. **27**, 1089; A. **289**, 46).

1 C. **OCTAHYDRIC ALCOHOLS: α-Gluco-octitol,** $CH_2OH[CHOH]_6.CH_2.OH$, m.p. 141°, is obtained from α-gluco-octose (p. 637, A. **270**, 98). **d-Manno-octitol,** $CH_2OH[CHOH]_6CH_2OH$, is produced from manno-octose, m.p. 258°. It dissolves with difficulty in water.

1 D. **NONOHYDRIC ALCOHOLS: Glucononitol,** $C_9H_{20}O_9$, m.p. 194°, is obtained from glucononose (A. **270**, 107).

2 AND 3. PENTA-, HEXA-, HEPTA-, AND OCTO-HYDROXY-ALDEHYDES AND KETONES

The long-known representatives of the first class of carbohydrates, which are produced by hydrolysis from the more complex carbohydrates, the saccharobioses (p. 657), like sucrose, maltose, and lactose, and from the polysaccharides, —*e.g.* starch, dextrin, cellulose, and others,—are pentahydroxyaldehydes and pentahydroxyketones. The most important sugar of the first class is dextrose, formed together with lævulose by the hydrolysis of sucrose. It also occurs as the final product of the hydrolysis of starch and of dextrin. In this connection it may be mentioned that dextrose and lævulose have already been referred to with ethyl alcohol, and in connection with its formation by alcoholic fermentation (p. 112).

The aldehyde character of these bodies is inferred from the ready oxidation of certain dextroses to monocarboxylic acids, and their reduction to hexahydric alcohols. *Zincke* (1880) was the first (B. **13**, 641 Anm.) to suspect that ketone alcohols were represented among the dextroses. *Kiliani*, in 1885, investigating the HNC additive products, proved that dextrose must be regarded as an aldehyde alcohol, and lævulose as a ketone alcohol. Hence, it is customary to distinguish *aldoses* and ***ketoses***. The same chemist also showed that arabinose was an aldopentose, and in so doing laid the basis of an extension of the idea of carbohydrates. What was lacking was a method of synthesis. It is true, sugar-like bodies had been obtained from formaldehyde (p. 636), but it was *E. Fischer* who first demonstrated that a well-defined sugar, α-acrose, could be isolated from it. This, as will be observed later, became in his hands the starting-point for the synthesis of dextrose and of lævulose.

By reducing the lactones of the polyhydroxycarboxylic acids to hydroxyaldehydes or aldoses, *E. Fischer* developed a method for the preparation of hydroxyaldehydes rich in carbon, or carbohydrates, from polyhydroxycarboxylic acids obtained synthetically from aldoses by the addition of hydrocyanic acid and subsequent hydrolysis. In this way carbohydrates, containing seven, eight, and nine carbon atoms in the molecule, were gradually built up (p. 616).

The dextroses mostly crystallize badly, and for their isolation and recognition phenylhydrazine was used. This, *E. Fischer* also discovered, gave the very best assistance. *Wohl* showed how the oximes of the aldoses could be utilized in their breaking down (p. 617).

The monose character of a compound is very much affected by its constitution, as aldehyde alcohol—CH(OH).CHO, or ketone alcohol—$CO.CH_2.OH$, in which the aldehyde and ketone group is directly combined with an alcohol group or groups. We thus have monoses containing not only *six*, but even a less or greater number of carbon and oxygen atoms. They are named according to the number of the oxygen atoms.

The simplest aldose, glycolyl aldehyde, $CH_2OH.CHO$, is an aldodiose. Glyceric aldehyde, $CH_2OH.CHOH.CHO$, and dihydroxyacetone, $CH_2OH.CO.CH_2OH$, represent an *aldotriose* and a *ketotriose* (p. 534). The aldehyde and ketone of erythritol is an *aldo-* and *keto-tetrose,* as just developed under the pentoses (p. 615). Following the latter are the *hexoses.* In this class belong the real sugars: *dextrose, lævulose,* and *galactose.*

In addition to the long-known hexoses—dextrose, lævulose, and galactose—many others have been discovered through *E. Fischer's* investigations, so that now the hexoses must be removed from the carbohydrate class, and be considered in immediate connection with their corresponding hexahydric alcohols. Then follow the *heptoses, octoses,* and *nonoses,* as well as the oxidation products of these aldehyde and ketone alcohols: the *polyhydroxymonocarboxylic acids,* the *polyhydroxyaldehydrocarboxylic acids,* and the *polyhydroxypolycarboxylic acids.* After the consideration of all these, the *higher carbohydrates,* the *saccharobioses,* and the *polysaccharides,* which are the anhydrides of the hexoses, will be brought together and fully discussed (p. 656).

2 A. PENTAHYDROXYALDEHYDES AND 3 A. PENTAHYDROXYKETONES: HEXOSES, DEXTROSES (GLUCOSES), MONOSES

Occurrence.—Some hexoses occur widely distributed in the free state in the vegetable kingdom, especially in ripe fruits. Esters of the glucoses (from γλυχυς, sweet) with organic acids are also frequently found in plants. They are called *glucosides*—*e.g.* salicin, amygdalin, coniferin, the tannins, which are dextrose esters of the tannic acids, etc. The glucosides are split into their components by ferments, acids, or alkalis.

Formations.—(1) They are formed by the hydrolytic decomposition of all di- and poly-saccharides, as well as of glucosides, by ferments (p. 113) (B. 28, 1429), or by boiling them with dilute acids. (2) d-Mannose and d-fructose have been made artificially by oxidizing d-mannitol. (3) A far more important method pursued in the formation of the dextroses is to reduce the monocarboxylic lactones with sodium amalgam in acid solution (*E. Fischer*, B. 23, 930). (4) Different optically inactive hexoses, particularly *a*-acrose or [d+l] fructose (p. 637), have been directly synthesized by the condensation of formic aldehyde, CH_2O, and glyceric aldehyde.

The [d+l] fructose, prepared in this way by *E. Fischer* is the parent substance for the complete synthesis of those forms of mannitol, dextrose, and lævulose, as occur in nature.

Properties.—The hexoses are mostly crystalline substances, very soluble in water, but dissolving with difficulty in alcohol. They possess a sweet taste. The representatives of the hexoses occurring in nature rotate the plane of polarization, when in solution, either to the left or to the right. The stereoisomers of the more important hexoses found in nature have been prepared artificially, and by the union of the corresponding dextro- and lævo-forms the optically inactive [d+l] varieties have been obtained. One of these, [d+l] fructose or α-acrose, as previously mentioned, has been directly synthesized.

Reactions.—The hexoses show the general reactions of the alcohols, the aldehydes, and the ketones.

(1) The alcoholic hydrogen of the dextroses can also be replaced by metals on treating them with CaO, BaO, and PbO, forming *saccharates*, which correspond with the alcoholates, and which are decomposed by carbon dioxide.

(2) On treating the alcoholic solutions of the hexoses with a little gaseous hydrochloric acid, their ethers result: glucosides of the alcohols (B. **26**, 2400; **29**, 2927).

(3) The hexoses combine with aldehydes, particularly with chloral, and with ketones, in the presence of inorganic acids, with an accompanying loss of water (B. **28**, 2496).

(4) The hydrogen of the hydroxyls can be readily replaced by acid radicals. A mixture of nitric and sulphuric acids (p. 323) converts them into esters of nitric acid (B. **31**, 73)—the nitro-compounds (p. 529). The acetyl esters are best obtained by heating the sugars with acetic anhydride and sodium acetate or $ZnCl_2$, whereby five acetyl groups are thus introduced (B. **22**, 2207). The pentabenzoyl esters are prepared with even less difficulty, it being only necessary to shake the hexoses with benzoyl chloride and sodium hydroxide (p. 324) (B. **22**, R. 668; **24**, R. 791).

An elementary analysis will not yield a positive conclusion as to the number of acyl groups that have entered compounds like those just mentioned. This is ascertained by first hydrolyzing them with titrated alkali solutions, or, better, with magnesia (B. **12**, 1531). Or, the acetic esters are decomposed by boiling them with dilute sulphuric acid. The acetic acid that distils over is then titrated (A. **220**, 217; B. **23**, 1442). The presence of hydroxyl in the dextroses may also be proved by means of phenylisocyanate, with which they form carbanilic esters (B. **18**, 2606; C. 1904, I. 1068).

(5) Alkyl sulphuric acids result on treating the dextroses with chlorosulphonic acid, $ClHSO_3$. This is similar to the behaviour of alcohols when exposed to like treatment (B. **17**, 2457).

The following reactions show the *aldehyde* and *ketone character* of the hexoses:

(1) By *reduction* (action of sodium amalgam) they become changed into hexahydric alcohols. d-Mannose and d-lævulose yield d-mannitol and d-sorbitol, galactose yields dulcitol, and d-sorbitol (and d-mannitol) seems to result from the reduction of d-dextrose (grape-sugar).

(2) The *oxidation* of the hexoses does not occur directly upon exposure to the air, but takes place readily by the aid of oxidizing

agents; hence they show feeble *reducing* power. They precipitate the noble metals from solutions of their salts, and even reduce ammoniacal silver solutions in the cold. A very marked characteristic is their ability to precipitate cuprous oxide from warm alkaline cupric solutions. One molecule of hexose precipitates about five atoms of copper, as Cu_2O. This is the basis of the gravimetric and volumetric method for the estimation of the dextroses by means of *Fehling's* solution. Only maltose and lactose, of the di- and polysaccharides, act directly upon the application of heat. The others must be first converted into dextroses (p. 657).

Fehling's solution is prepared by dissolving 34·65 grams of crystallized copper sulphate in water, then adding 200 grams Rochelle salt and 600 c.cm. of NaOH (sp.gr. 1·1200), and diluting the solution to 1 litre. 0·05 gram of hexose is required to reduce completely 10 c.c. of this liquid. The end reaction is rather difficult to recognize, hence it is frequently recommended to estimate the separated cuprous oxide gravimetrically (B. **13**, 826; **27**, R. 607, 760; **29**, R. 802). Consult B. **23**, 1035, for Soldaini's suggestion of using a copper carbonate solution for the estimation of the hexoses.

The oxidation-products of the hexoses formed by the action of *Fehling's* solution varies according to the concentration, and consist partly of pentahydroxycarboxylic acids (p. 647) and partly of acids of lower carbon content down to formic and carbonic acids (A. **357**, 259).

The hexoses are converted into their corresponding monocarboxylic acids (p. 647) by moderated oxidation with chlorine and bromine water, or silver oxide. The ketoses are more stable than the aldoses towards bromine and iodine solutions.

More energetic oxidation changes them (as well as nearly all carbohydrates) to saccharic or mucic acids. Lactose yields both acids at the same time.

(3) The aldohexoses produce a red coloration in a sulphite-fuchsine solution (*Schiff's* reagent), whilst the ketohexoses, like lævulose and sorbinose, do not show this reaction (B. **27**, R. 674). The penta-acetyl and pentabenzoyl derivatives of the dextroses and galactoses no longer show the aldehyde character (B. **21**, 2842; **22**, R. 669). Hence, it is supposed that the hexoses possess a constitution like ethylene oxide or a lactone (B. **21**, 2841; **22**, 2211; **23**, 2114; **26**, 2403; **28**, 3080).

(4) The aldoses yield mercaptals with mercaptans, in the presence of hydrochloric acid (B. **27**, 673).

(5) Oximes are produced when alcoholic hydroxylamine acts on the hexoses. To break down the aldoses, the acetyl hydroxy-acid nitriles, obtained from the aldoximes and acetic anhydride, are split into hydrocyanic acid and acetyl pentoses (p. 617) (B. **24**, 993; **26**, 730).

(6*a*) Osamines are formed when the hexoses are acted on with methy alcoholic ammonia.

(6*b*) The hexoses and aniline, as well as its homologues, yield the anilides—*e.g* dextrose anilide, $CH_2OH[CHOH]_4CH:NC_6H_5$, which form cyanides with HNC—*e.g.* anilidodextrose cyanide, $CH_2OH[CHOH]_4.CH.(CN)NHC_6H_5$ (B. **27**, 1287).

(7) Hydrazine converts the aldohexoses into aldazines, and the ketohexoses into ketazines (p. 228) B. **29**, 2308).

(8) The phenylhydrazine derivatives are especially interesting (pp. 213, 356). (*a*) If one molecule of the phenylhydrazine, as

acetate, is allowed to act, the first product will be a *hydrazone*, $C_6H_{12}O_5$.-($N.NH.C_6H_5$). This class of compounds dissolves readily in water (with the exception of those derived from the mannoses and the higher dextroses, B. **23**, 2118). They generally crystallize from hot alcohol in colourless needles. Cold concentrated hydrochloric acid resolves them into their components. Benzaldehyde is also an excellent reagent for the decomposition of the phenylhydrazones (A. **288**, 140).

With unsym.-diphenylhydrazine the slightly soluble diphenylhydrazones are mainly formed (B. **23**, 2619, etc.). Benzyl phenylhydrazine is very well suited for the preparation of pure sugars: the benzyl phenylhydrazones are decomposed by formaldehyde, whereby the sugar is liberated and *formaldehyde benzyl phenylhydrazone*, m.p. 41°, is formed (B. **32**, 3234). Also, unsym.-methyl phenylhydrazine, bromophenylhydrazine, and β-naphthylhydrazine have been recommended from time to time for the precipitation and separation of the sugars (B. **35**, 4444, etc.).

(*b*) In the presence of an excess of phenylhydrazine the hexoses, like all dextroses, combine with two molecules of it upon application of heat and form the **osazones** (*E. Fischer*):

$$C_6H_{12}O_6+2H_2N.NH.C_6H_5=\underset{\text{Dextrosazone.}}{C_6H_{10}O_4(N.NH.C_6H_5)_2}+2H_2O+H_2.$$

The reaction is carried out by adding two parts of phenylhydrazine, two parts of 50 per cent. acetic acid, and about twenty parts of water to one part of dextrose. This mixture is digested for about one hour upon the water bath. The osazone then separates in a crystalline form (B. **17**, 579; **20**, 821; **23**, 2117). In this reaction a hydrazone is first produced, and one of its alcohol groups, adjacent to either an aldehyde or ketone group, is oxidized to CO, two hydrogen atoms in the presence of excess of phenylhydrazine appearing as aniline and ammonia; the aldehydo- or keto-group, which is formed, reacts further on a second molecule of phenylhydrazine. *One* and the *same* **dextrosazone**, $CH_2OH.(CHOH)_3.C(N_2HC_6H_5).CH(N_2HC_6H_5)$ (B. **23**, 2118), is thus obtained from d-mannose, d-dextrose, and d-lævulose. This would indicate that the four carbon atoms which did not enter into reaction with phenylhydrazine contain the atoms or groups of atoms with which they are combined similarly arranged.

It is of importance in the separation of aldoses and ketoses that with unsym.-alkyl phenylhydrazines, such as α-methyl phenylhydrazine, only the ketoses yield the yellow *methyl phenyl osazones*, whilst the aldoses give the simple colourless hydrazones (B. **35**, 959, 2626).

The osazones are yellow-coloured compounds (see Tartrazine, p. 608). They are usually insoluble in water, dissolve with difficulty in alcohol, and crystallize quite readily. When dextrosazone is reduced with zinc dust and acetic acid it becomes converted into isodextrosamine (p. 637). Nitrous acid converts the latter into lævulose (B. **23**, 2110). The reformation of the hexoses from their osazones is readily effected by digestion with concentrated hydrochloric acid; they are then resolved into phenylhydrazine and the **osones** (B. **22**, 88; **23**, 2120; **35**, 3141):

$$\underset{\text{Dextrosazone.}}{C_6H_{10}O_4(N_2H.C_6H_5)_2}+2H_2O=\underset{\text{Dextrosone.}}{CH_2OH.(CHOH)_3.CO.COH}+2N_2H_3.C_6H_5.$$

The osones dissolve readily in water, and have not been obtained pure. They are also formed from aldoses and ketoses directly by oxidation with H_2O_2 in presence of ferrous salts (C. 1902, I. 859). They combine, like keto-aldehydes, with two molecules of phenylhydrazine and form osazones. They are converted into ketoses by reduction, as when digested with zinc dust and acetic acid. In this way fructose is prepared from dextrosazone (B. **3**, 2121).

The osones, like all orthodicarbonyl compounds, yield quinoxalines (B. **23**, 2121) with the orthodiamines. The dextroses also combine directly with the ortho-phenylene diamines (B. **20**, 281).

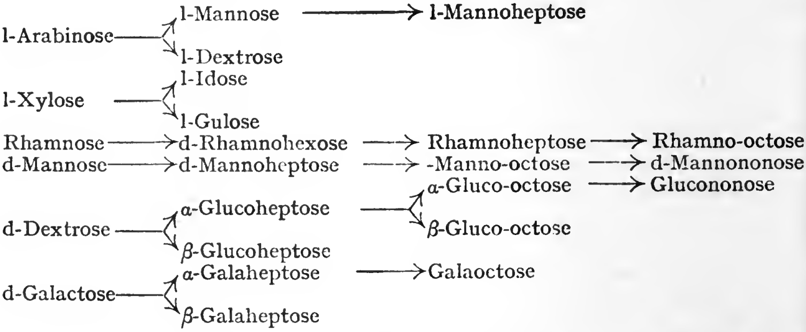
(*c*) Benzoyl hydrazide, or benzhydrazide, $NH_2NH.COC_6H_5$, combines with the aldohexoses to benzosazones, which contain four benzhydrazide residues (B. **29**, 2310):

$$C_6H_{12}O_6+4NH_2NH.COC_6H_5=C_6H_6O_2(N.NH.COC_6H_5)_4+4H_2O+3H_2.$$

Synthetic and Degradation Reactions of the Hexoses.

(1) Being aldehydes or ketones, the hexoses combine with hydrocyanic acid, forming cyanhydrins, which yield monocarboxylic acids (p. 615). Their lactones can in turn be reduced to aldoses, whereby the synthesis of the monoses is achieved. Usually in the hydrogen cyanide addition the nitriles of both the acids possible theoretically are produced, but not in equal amounts.

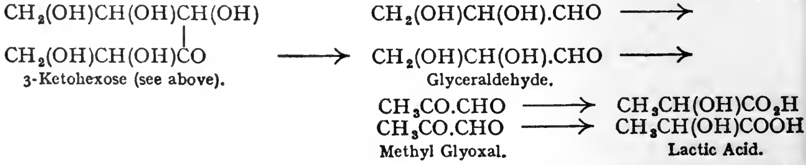
These two reactions: (1) the hydrogen cyanide addition to the aldoses, and (2) reduction of the lactones of the hydroxycarboxylic acids, obtained from the nitriles, by means of sodium amalgam make possible the genetic connection of the following aldoses (B. **27**, 3192):



(2) The *degradation of the aldohexoses to aldopentoses* through their oximes, and by oxidation with H_2O_2 has already been discussed as a special case of a general reaction (p. 618).

(3) The *behaviour of the hexoses with alkalis*, such as the hydroxides of sodium, calcium, lead, zinc, etc., is noteworthy. Dilute alkalis strongly depress the optical rotation of the naturally occurring hexoses, as a result of partial isomerisation to the stereomeric aldoses and ketoses as far as the point of equilibrium (see B. **28**, 3078; A. **357**, 294). *Mannose, dextrose*, and *lævulose* yield a mixture of these three hexoses, together with *ψ-lævulose* and *glutose* (or 3-*ketohexose?*); similarly, *galactose* may yield l-*sorbose*, d-*tagatose*, *talose*, and *galtose* (or 3- *ketohexose?*).

Longer action of alkalis decomposes this mixture of hexoses mainly into lactic and other acid (B. **41**, 1009). It is probable that the formation of lactic acid results from the initial formation of glyceraldehyde, which loses oxygen and is changed into methyl glyoxal (p. 348), which in turn changes into lactic acid:



$$\begin{array}{lcl} CH_2(OH)CH(OH)CH(OH) & & CH_2(OH)CH(OH).CHO \longrightarrow \\ \qquad\qquad\qquad\qquad\quad | & & \\ CH_2(OH)CH(OH)CO & \longrightarrow & CH_2(OH)CH(OH).CHO \longrightarrow \end{array}$$

3-Ketohexose (see above). Glyceraldehyde.

$$\begin{array}{lcl} CH_3CO.CHO & \longrightarrow & CH_3CH(OH)CO_2H \\ CH_3CO.CHO & \longrightarrow & CH_3CH(OH)COOH \end{array}$$

Methyl Glyoxal. Lactic Acid.

The formation of methyl glyoxal, according to the above scheme, is made the more probable by the action of zinc ammonium hydroxide on dextrose producing methyl glyoxaline, which should be prepared from methyl glyoxal and ammonia (p. 346) (B. **39**, 3886).

In addition to the products of reaction between hexoses and alkalis, there are also formed—particularly when lime-water is employed—*saccharic acids* (p. 620), the production of which results partly from an intra-molecular wandering of oxygen, and also in a change of the form of the normal carbon chain (comp. A. **357**, 294; B. **41**, 469, 1012).

If air be passed through an alkaline solution of the hexoses, or if H_2O_2 be added, mainly formic acid is formed, together with higher molecular non-volatile acids, the formation of which is explained by partial decomposition of the hexose into formaldehyde and the oxidation of the latter into its acid (B. **39**, 4217) (see also p. 628; *Fehling's* solution).

(4) *Fermentation of the Hexoses.*—The ready fermentation of the hexoses when exposed to the action of *schizomycetes* is characteristic of them. They undergo various decompositions.

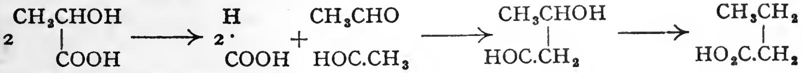
(*a*) The *alcoholic fermentation* of the hexoses is the most important decomposition of some of the aldohexoses which is induced by yeast cells. d-Dextrose or grape-sugar, d-mannose, d-galactose, and the ketohexoses, d-fructose or fruit-sugar, are acted on in this manner. This subject was examined in detail under ethyl alcohol (p. 112). The other hexoses are not altered by the yeast fungi (B. **27**, 2030).

(*b*) In the *lactic acid* fermentation, the hexoses, lactose, and gums decompose directly into lactic acid:

$$C_6H_{12}O_6=2C_3H_6O_3$$

the active agents being various kinds of fission-fungi—*schizomycetes, bacilli,* and *micrococci.* Decaying proteïn matter (decaying cheese) is requisite for their development, which only proceeds in liquids which are not too acid (p. 363). The temperature most favourable varies from 30–50°. Prolonged fermentation causes the lactic acid salts which are formed to undergo

(*c*) *Butyric acid fermentation,* which is due to the action of other bacilli (p. 259). This fermentation is explained chemically by the decomposition of lactic acid into formic acid and acetaldehyde (p. 199), the condensation of the latter into aldol (p. 338) which changes into butyric acid with the intra-molecular wandering of an oxygen atom:



$$2\,\begin{array}{c}CH_2CHOH\\|\\COOH\end{array}\longrightarrow 2\cdot\begin{array}{c}H\\COOH\end{array}+\begin{array}{c}CH_3CHO\\HOC.CH_3\end{array}\longrightarrow\begin{array}{c}CH_3CHOH\\|\\HOC.CH_2\end{array}\longrightarrow\begin{array}{c}CH_3CH_2\\|\\HO_2C.CH_2\end{array}$$

(*d*) *Citric Acid fermentation* of dextrose (p. 610).

(*e*) In *mucous fermentation* chains of cells are to be found, which convert dextrose into a mucoid, gummy substance, with the generation of CO_2. d-Mannitol and lactic acid are also formed.

2A. ALDOHEXOSES

(1) **Mannose,** $C_6H_{12}O_6$, is the aldehyde of mannitol. Like the latter, it exists in three forms (p. 610): dextro-, lævo-, and inactive [d+l] mannose (spacial formulæ, p. 641; constitution, p. 644).

d-*Mannose, Seminose,* m.p. 136°, was first prepared by oxidizing ordinary d-mannitol, together with d-fructose, with platinum black or nitric acid (B. **22**, 365). It is also obtained from salep mucilage (from salep, the tubers of certain orchids), and most easily from seminine (reserve-cellulose), occurring in different plant seeds, particularly in the shells of the vegetable ivory nut, when this is boiled with dilute sulphuric acid (hence called *seminose*) (B. **22**, 609, 3218). d-Mannonic acid yields it upon reduction. It reduces *Fehling's* solution, and is fermented by yeast (B. **22**, 3223). When treated with alkalis it changes partly to d-dextrose and d-fructose (p. 630). Its *hydrazone,* m.p. 195°, dissolves with difficulty in water. Benzaldehyde decomposes it into pure crystallized d-mannose (B. **29**, R. 913). Its *osazone,* $C_6H_{10}O_4(N_2HC_6H_5)_2$, is identical with d-dextrosazone. d-*Mannosoxime*, m.p. 184° (B. **24**, 699). Nascent hydrogen converts it into d-mannitol. Bromine oxidizes it to d-mannonic acid. Hydrocyanic acid causes it to pass into d-mannoheptonic acid (p. 651).

Methyl d-Mannose, $C_6H_{11}O_6.CH_3$, m.p. 190°, $[\alpha]_D^{20°}=+79·2$ (B. **29**, 2928); *pentanitrate*, m.p. 81° (B. **31**, 76).

l-Mannose results when l-mannonic lactone is reduced (p. 649; B. **23**, 373). It is very similar to the preceding compound, but is lævo-rotatory, and is fermented with more difficulty. Its *hydrazone*, m.p. 195°, also dissolves with difficulty. It unites with two molecules of phenylhydrazine to form l-dextrosazone. It becomes converted into l-mannitol by reduction (B. **23**, 375). *Methyl l-Mannose*, m.p. 190°, $[\alpha]_D^{20°}=-79·4°$ (B. **29**, 2929).

[d+l] **Mannose** is formed (1) by the oxidation of α-acritol or [d+l] mannitol (p. 623), which can be obtained by the reduction of synthetic α-acrose or [d+l] fructose; (2) by the reduction of inactive [d+l] mannonic lactone; (3) by the splitting of a mixture of d- and l-mannose phenylhydrazone by formaldehyde (C. 1903, I. 1217). It is quite similar to the two preceding compounds, but is inactive. Its *hydrazone*, m.p. 195°, dissolves with difficulty, and is inactive. Its *osazone* is [d+l]-dextrosazone, identical with α-acrosazone. Yeast decomposes it, the d-mannose is fermented, and l-mannose remains (B. **23**, 382). *Methyl* [d+l] *Mannose*, m.p. 165°, is obtained from the solution of equal quantities of its components at 15°. Below 8° the components crystallize out separately (B. **29**, 2929).

(2) **Dextrose**, $C_6H_{12}O_6$, is probably the aldehyde of sorbitol, and occurs as dextro-, lævo-, and inactive [d+l] dextrose (p. 642).

d-**Dextrose**, or *Grape Sugar*, formerly called *glucose*, m.p. with one molecule of water 86°, anhydrous, 146°, occurs (with lævulose) in many sweet fruits and in honey; also in the urine in *Diabetes mellitus*. It is formed by the hydrolytic decomposition of polysaccharides (sucrose, starch, cellulose) and glucosides. It is prepared on a large scale by boiling starch with dilute sulphuric acid (see B. **13**, 1761). *The synthesis of dextrose has been made possible by the production of dextrose in the reduction of the lactone of d-gluconic acid* (p. 637).

Commercial dextrose is an amorphous, compact mass, containing only about 60 per cent. dextrose, along with a dextrin-like substance, *gallisin*, $C_{12}H_{24}O_{10}$, which is not fermentable (B. **17**, 2456).

The best method for preparing pure crystallized dextrose consists in adding to 80 per cent. alcohol mixed with $\frac{1}{13}$ volume of fuming hydrochloric acid, finely pulverized sucrose, as long as the latter dissolves on shaking (J. pr. Ch. [2] **20**, 244).

Dextrose crystallizes from water at the ordinary temperature, or dilute alcohol, in nodular masses, with one molecule of water, which it loses at 110°. At 30–35° it crystallizes from its concentrated aqueous solution, and from its solution in ethyl or methyl alcohol, in anhydrous, hard crusts (B. **15**, 1105).

Dextrose is not quite as sweet to the taste as sucrose, and is employed to "improve" wines.

When the ordinary crystalline dextrose is dissolved in water without the assistance of heat, it shows $[\alpha]_D=+106°$; if it be boiled for twenty-four hours, or if a trace of alkali be added to it the rotation falls to one half, $[\alpha]_D=+53$. An equilibrium is here set up, and the more highly rotating α-dextrose can be separated. But if melted dextrose be heated to 110° another modification—γ-dextrose, $[\alpha]_D=+22·6°$ is obtained, which, in aqueous solution, slowly rises to $[\alpha]_D=+53°$. In pyridine solution dextrose (m.p. 146°) also exhibits *birotation;* if this solution be treated with acetic anhydride at 0° mainly α-pentacetyl dextrose (p. 634) will be obtained. If, however, the solution be heated till it shows the smaller angle of rotation, then β-pentacetyl dextrose will be obtained by the same reagent. Further, the highly-rotating form of α-methyl glucose (below), when hydrolyzed by the ferment maltase, yields the more highly rotating α-dextrose; the lower β-form of methyl dextrose gives, with emulsin, the lower rotating γ-dextrose.

It is, therefore, probable that there are two interconvertable stereomeric forms of dextrose having a alkylene oxide or lactone structure

$$CH_2(OH)CH(OH)CH(O)CH(OH)CH(OH)CH(OH)$$

from which the stereomeric alkyl dextrose, pentacetyl dextrose, etc., are derived (A. **331**, 359).

In general, dextrose shows all the properties of the aldoses; *syn-* and *anti-* (α- and β-) d-*dextrose phenylhydrazine*, m.p. 160° and 141°, is lævo-rotatory (A. **362**, 78).

d-Dextrosazone, α-variety, m.p. 145°; β-variety m.p. 205° (B. **41**, 75) is lævo-rotatory in aqueous solution. *It may also be prepared from d-mannose and d-fructose*, as well as from dextrosamine and isodextrosamine. Concentrated hydrochloric acid converts d-dextrosazone into phenylhydrazine and *dextrosone*, $C_6H_{10}O_6$ (p. 629); which regenerates d-dextrosazone with two molecules of phenylhydrazine. It is a non-fermentable syrup (C. 1902, I. 895), and if it be reduced with zinc and acetic anhydride, is converted into d-fructose (B. **22**, 88).

Dextrose is converted, by reduction with sodium amalgam, into d-sorbitol with some d-mannitol, by acid oxidation, into d-gluconic acid and d-saccharic acid. Alkalis convert it partly into d-mannose and d-fructose (B. **28**, 3078) together with ψ-fructose and glutose (p. 630); prolonged action of alkalis produces lactic and other acid products (p. 630).

Milk of lime converts dextrose partially into saccharic acid (p. 620). Alkalis and benzhydrazide break up the dextrose molecule, and form benzoyl osazone of glyoxal and methyl glyoxal (B. **31**, 31). Ammonium zinc hydroxide gives methyl glyoxaline (p. 630). For the products of alkaline oxidation of dextrose, see pp. 628, 631, and B. **27**, R. 788.

The quantitative determination of dextrose may be effected by means of alkaline mercury cyanide and mercury potassium iodide solutions (B. **39**, 504).

Saccharates.—With barium and calcium hydroxide solutions dextrose forms saccharates, like $C_6H_{12}O_6.CaO$, and $C_6H_{12}O_6.BaO$, which are precipitated by alcohol. With NaCl it forms large crystals, $2C_6H_{12}O_6.NaCl+H_2O$, which sometimes separate in the evaporation of diabetic urine.

Alkyl d-Glucosides.—The glucosides are the ethereal derivatives of the dextroses. Those of dextrose particularly are frequently found in the vegetable kingdom. They generally contain the residues of aromatic bodies, and therefore will be discussed later. The simplest glucosides are the alkyl ethers of the sugars, which are produced in the action of HCl on alcoholic sugar solutions (B. **28**, 1151). *Fehling's* solution and phenylhydrazine at 100° do not affect the alkyl d-dextroses. However, they are decomposed into their components when boiled with dilute acids, or by ferments (p. 631). These properties argue for the *alkylene oxide* formulæ for the alkyl dextroses (p. 632):

α-and β-*Methyl Dextrose*, $C_6H_{11}O_6.CH_3$, m.ps. 165° and 107°, are stereochemically different, the α-compound being dextro-rotatory $[\alpha]_D + = 157{\cdot}6°$, the β-body being lævo-rotatory $[\alpha]_D = -31{\cdot}85°$ (B. **34**, 2899). They are formed together by the action of hydrochloric acid and methyl alcohol on dextrose, and can also be obtained from α- and β-aceto-chloro- or bromo-dextrose, methyl alcohol and silver carbonate, and hydrolyzing the resulting *tetra-acetyl methyl dextrose*. β-Methyl dextrose is formed from dextrose, dimethyl sulphate and alkate (B. **34**, 957, 2885; C. 1905, I. 1593). The α-compound is decomposed by invertin, but not the β-substance, which, however, is attacked by emulsin (B. **27**, R. 885; **27**, 2479, 2985; **28**, 1145). If α-methyl dextrose be alkylized by means of silver oxide and iodomethane in methyl alcohol there is formed, among other compounds, α-*Methyl Tetramethyl Dextrose*, b.p.$_{17}$ 145°. Hydrolysis converts this into *Tetramethyl Dextrose*, $CH_2OCH_2CH(OCH_3)CH(O)CH(OCH_3)CH(OCH_3)CHOH$, m.p. 89°, b.p.$_{26}$

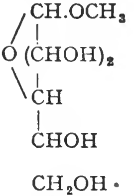
182–185°. It is also found by the hydrolysis of methylated saccharose and maltose, also from pentamethyl salicin (Vol. II.) (C. 1903, II. 346; 1904, II. 891; 1906, II. 345; 1908, I. 1043). It is a reducing substance, exhibits mutarotation, and is converted by oxidation into tetramethyl gluconic lactone.

β-Phenyl Glucoside, $C_6H_{11}O_6.C_6H_5$, m.p. 175°, is formed from β-acetochlorodextrose and sodium phenolate (B. **34**, 2898).

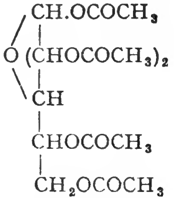
α- and *β-Pentacetyl Dextrose*, $C_6H_7O(OCOCH_3)_5$, m.ps. 112° and 131°.

α- and *β-Acetochlorodextrose*, $C_6H_7O(OCOCH_3)_4Cl$, m.ps. 64° and 74°.

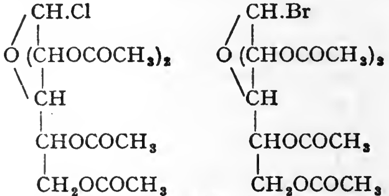
α- and *β-Acetobromodextrose*, $C_6H_7O(OCOCH_3)_4Br$, m.ps. 80° and 89°, are closely connected with the α- and β-alkyl d-dextroses and must therefore possess a similar structure. α- and β-pentacetyl dextrose, which have lost their aldehidic character are formed from dextrose and acetic anhydride with zinc chloride, sodium acetate or pyridine (see above); zinc chloride causes the β-variety to change into the α-form. When treated with liquid HCl or HBr one acetyl group is exchanged for a halogen atom and acetochloro- and acetobromo-dextroses result. The β-acetohalogen-dextroses were first formed directly from dextrose by the action of acetyl chloride or bromide; the β-acetochlorodextrose being also obtained from pentacetyl dextrose, PCl_5 and $AlCl_3$. They are remarkable for the reactivity of the halogen atom, which can readily be replaced by the acetyl, alkoxyl, and $O.NO_2$-groups. In the latter case, *Acetonitrodextrose*, $C_6H_7O(OCOCH_3)_4(.ONO_2)$, m.p. 151°, is formed, which crystallizes well. It is also formed from β-pentacetyl dextrose and nitric acid (A. **331**, 381). The following formulæ express the probable structure of these compounds, in which the α- and β-varieties are considered as being stereomeric (p. 633) (B. **34**, 957, 2885, 3205; **35**, 833; C. 1902, I. 180):



Methyl Glucoside.



Pentacetyl Dextrose.



Acetochloro- and Acetobromo Dextrose.

d-*Dextrose Mercaptal*, $C_6H_{12}O_5(SC_2H_5)_2$, m.p. 127°, is obtained from d-dextrose, mercaptan, and HCl. d-*Dextrose Ethylene Mercaptal*, $C_6H_{12}O_5{:}S_2C_2H_4$, m.p. 143°. d-*Dextrose Trimethylene Mercaptal*, $C_6H_{12}O_5{:}S_2C_3H_6$, m.p. 130°. d-*Dextrosebenzyl Mercaptal*, $C_6H_{12}O_5(SCH_2.C_6H_5)_2$, m.p. 133° (B. **29**, 547).

Methylene Dextrose, $C_6H_{10}(CH_2)O_6$, m.p. 187° (B. **32**, 2585).

d-*Dextrose Monacetone*, $C_6H_{10}O_6{:}C(CH_3)_2$, m.p. 156°. d-*Dextrose Diacetone*, $C_6H_8O_6[C(CH_3)_2]_2$, m.p. 107° (B. **28**, 2496).

d-*Chloralose*, m.p. 189°, and d-*Parachloralose*, $C_8H_{12}Cl_3O_6$, m.p. 227°, are two isomeric bodies, produced by the rearrangement of d-dextrose with chloral (B. **27**, R. 471; **29**, R. 177).

d-**Dextrosoxime**, $C_6H_{12}O_5NOH$, m.p. 137°, when acted on with acetic anhydride and sodium acetate, yields pentacetyl d-glucononitrile (p. 649), from which d-arabinose was isolated (p. 618). These are reactions which render possible the breaking down of the aldoses. Reduction to glucamine (p. 624).

d-*Dextrose Aminoguanidine Chloride*, $C_6H_{12}O_5.CN_4H_4.HCl$, m.p. 165°, is obtained from d-dextrose and aminoguanidine hydrochloride (B. **27**, 971).

d-*Dextrose Semicarbazone*, m.p. 175° with decomposition (B. **31**, 2199, footnote).

d-*Dextrose Aldazine*, $CH_2OH[CHOH]_4CH{:}N{-}N{:}CH[CHOH]_4CH_2OH$, is very hygroscopic (B. **29**, 2308).

l-**Dextrose**, m.p. 143°, is formed when the lactone of l-gluconic acid is reduced. It is perfectly similar to dextrose, but is lævo-rotatory, $[\alpha]_D = -51{\cdot}4°$. Its dextrosazone is, however, dextro-rotatory. Its *diphenylhydrazone*, $C_6H_{12}O_5{:}N.N(C_6H_5)_2$, m.p. 163°, dissolves with difficulty (B. **23**, 2618).

[d+l]-**Dextrose** results from the union of d- and l-dextrose, and by the reduction of [d+l]-gluconic lactone. [d+l]-*Dextrosazone*, m.p. 218°, is also formed from inactive mannose, and from synthetic α-acrose, or [d+l]-lævulose (p. 637) (B. **23**, 383, 2620).

(3) **Gulose**, $CH_2OH[CHOH]_4CHO$ (space formula, p. 642), the second

aldehyde of sorbitol, is likewise known in its three modifications. They are formed by the reduction of the lactones of the three gulonic acids (p. 640), and by further reduction yield the sorbitol. They are syrups and are not fermented by yeast. The name gulose is intended to indicate their relationship to glucose (the old name for dextrose), the first aldehyde of sorbitol. l- and [d+l] *Gulose Phenylhydrazone*, m.p. 143°. l-*Gulosazone*, m.p. 156°. [d+l] *Gulosazone*, m.p. 157–159°.

(4) d- and l-**Idoses** are prepared by the reduction of the idonic acids or their lactones (p. 650). They yield d- and l-iditol on reduction (p. 624) (space formula, p. 642).

(5) **Galactose,** the aldehyde of inactive dulcitol (p. 624), formed by internal compensation, is known in three varieties. The [d+l] *Galactose*, m.p. 140–142°, results from the reduction of the lactone of [d+l] galactonic acid, and when fermented with beer yeast it becomes l-galactose; *phenylhydrazone*, m.p. 158–160°; *osazone*, m.p. 206°.

l-**Galactose,** m.p. 163° (p. 642), yields dulcitol on reduction, and mucic acid when it is oxidized; *phenylhydrazone*, m.p. 158–160°; *osazone*, m.p. 206°.

d-**Galactose,** $CH_2OH[CHOH]_4CHO$, m.p. 160°, is dextro-rotatory and fermentable (B. **21,** 1573) (see also p. 642; B. **27,** 383). It is formed along with d-dextrose in the hydrolysis of lactose, of *galactitol*, $C_9H_{18}O_7$, a beautifully crystallized body occurring in yellow lupins (B. **29,** 896; and of various gums (called *galacrans*) (B. **20,** 1003), which nitric acid oxidizes to mucic acid. It is prepared by boiling lactose with dilute sulphuric acid (A. **227,** 224). Dulcitol is formed by its reduction, and galactonic and mucic acids by its oxidation. HNC and hydrochloric acid change it to galactose carboxylic acid (p. 651). When heated with alkalis it is converted into l-*sorbose*, d-*tagatose*, d-*talose*, etc. (p. 636). α- and **β-Methyl d-Galactose,** m.p. 111° and 173–175°. Emulsin decomposes the second (B. **28,** 1429). It stands in the same relation to *pentacetyl galactose*, m.p. 142°, *acetochlorogalactose*, m.p. 76° (82°), *acetobromogalactose*, m.p. 83°, and *acetonitrogalactose*, m.p. 94°, as do the corresponding dextrose derivatives (p. 634). α- and *β-Methyl Tetramethyl-Galactose*, etc., form, b.p.$_{11}$ 137°, β-form, m.p. 45° (C. 1904, II. 892). α- and *β-Galactose Pentanitrate*, m.ps. 115° and 72° (B. **31,** 74). *Galactochloral*, m.p. 202° (B. **29,** 544); *oxime*, m.p. 175°, see Pentacetyl Galactonic Nitrile (p. 650); *osazone*, m.p. 193°. *Galactose Amidoguanidine Chloride* (B. **28,** 2613). The *Ethyl Mercaptal*, m.p. 127°; *Ethylene Mercaptal*, m.p. 149° (B. **29,** 547).

(6) d-**Talose,** $CH_2OH[CHOH]_4CHO$, is formed by the reduction of the lactone of d-talonic acid (p. 650) (B. **24,** 3625). Space formula, p. 643; comp. B. **27,** 383.

(7) **Rhamnohexose,** *Methyl Hexose*, $CH_3.CHOH(CHOH]_4.CHO$, m.p. 181°, is produced by the reduction of rhamnose carboxylic acid; *osazone*, m.p. 200°. It forms methyl heptonic acid with hydrocyanic and hydrochloric acids.

3A. KETOHEXOSES

1. **Fructose,** $CH_2OH[CHOH]_3.CO.CH_2OH$, occurs as d-, l-, and [d+l] varieties.

d-**Fructose, Lævulose, Fruit Sugar** (space formula, p. 646), m.p. 95°, occurs in almost all sweet fruits, together with dextrose. It was discovered in 1847 by *Dubrunfaut*. It is formed, (1) together with an equal amount of dextrose, in the decomposition of sucrose, and is separated from the latter through the insolubility of its calcium compound (B. **28,** R. 46). As fructose rotates the plane of polarization more strongly towards the left than dextrose does to the right, the decomposition of the d-sucrose leads to the formation of a lævo-rotatory *invert sugar* solution (p. 113).

(2) On heating inulin with water to 100° for twenty-four hours, it is changed exclusively to lævulose (A. **205,** 162; B. **23,** 2107). It can also be obtained from secalose, a carbohydrate contained in green rye plants (B. **27,** 3525).

(3) It is formed together with d-mannose in the oxidation of

d-mannitol; also (4) from d-dextrosazone, which has been prepared from d-dextrose, as well as from d-mannose. *This method of formation allies fructose genetically with d-dextrose and d-mannose* (p. 631). Hence, in spite of its lævorotation of $[\alpha]_D = -92.3°$ (A. **25**, 166), it is called d-fructose. Fructose crystallizes with difficulty, and dissolves with greater difficulty than dextrose. By reduction it yields d-mannitol and d-sorbitol; and when oxidized the products are d-erythronic acid (p. 598) and glycollic acid. It is partially converted into d-dextrose and d-mannose by alkalis (p. 631). Heated under pressure with a little oxalic acid, d-fructose becomes β-hydroxy-δ-methylfurfural (B. **28**, R. 786). It yields d-fructose carboxylic acid (p. 651) when treated with hydrocyanic and hydrochloric acids; this may be reduced to methyl butyl acetic acid, whereby the constitution of fructose is proved. Phenylhydrazine and fructose yield d-dextrosazone.

Methyl d-Fructose (B. **28**, 1160). *Lævulochloral*, m.p. 228° (B. **29**, R. 544).

α- and β-Lævulosan Trinitrate, $C_6H_7O_5(NO_2)_3$, m.ps. 137° and 48° (B. **31**, 76).

l-Fructose is produced by fermenting [d+l] fructose (α-acrose) with yeast (B. **23**, 389).

[d+l] **Fructose** or **α-Acrose.**—The resolvable fructose modification is, by virtue of its own synthesis, of the greatest importance in the synthesis of sugars (p. 637).

Historical.—Methylenitan, the first compound resembling the sugars that was prepared, was obtained by *Butlerow* (1861), who condensed trioxymethylene (p. 199) with lime-water. *O. Loew* (1885) obtained *formose*, $(CH_2OH)_2$-$C(OH)CH(OH).CO.CH_2OH$ (?) (J. pr. Ch. **33**, 321; C. 1897, I. 803, 906) in an analogous manner from hydroxymethylene, and somewhat later the fermentable *methose*, by the use of magnesia (B. **22**, 470, 478). *E. Fischer* considers these three compounds mixtures of different dextroses, among which α-acrose occurs (B. **22**, 360). The latter, together with β-acrose, is obtained more easily by the action of barium hydroxide on *acroleïn bromide*, $C_3H_5OBr_2$ (*E. Fischer* and as well as from glyceric aldehyde, $CH_2OH.CHOH.CHO$, or dihydroxyacetone, *J. Tafel* (B. **20**, 1093)), and by the condensation of so-called *glycerose* (p. 534), $CH_2OH.CO.CH_2OH$, by condensation (B. **23**, 389, 2131; **35**, 2630). Reduction converts [d+l]-fructose or α-acrose into [d+l]-mannitol or α-acritol.

(2) *d*-**Tagatose**, $C_6H_{12}O_6$, m.p. 124°, is formed by the action of potassium hydroxide solution on galactose. It is a ketose. d-Tagatose, galactose, and talose yield the same osazone, and therefore bear the same relation to one another as lævulose, dextrose, and mannitol. The above-mentioned alkali treatment also produces **Galtose** and

(3) **l-Sorbose**, *ψ-Tagatose*, m.p. 154°, the optical isomer of

d-Sorbose, *Sorbinose*, $C_6H_{12}O_6$, m.p. 154°. This is obtained from d-sorbitol (p. 624) by the action of *Bacterium xylinum*, and unites with l-sorbose to form [d+l] *sorbose*. Reduction with sodium amalgam gives d- and l-sorbose, as well as d- and l-sorbitol and d- and l-iditol (p. 624). They are to the guloses and idoses what the lævuloses are to the dextroses and mannoses, and are also ketoses (C. 1900, I. 758).

Hexose and *Pentose Imines and Amines*. Ammonia unites with the hexoses with loss of water to form *dextrosimine*, *mannosimine*, *galactosimine*, and forms with the pentoses *arabinosimine*, *xylosimine*, etc., which are decomposed by acids into the original aldoses and ammonia. Isomeric with the hexosimines is

d-**Dextrosamine**, *Chitosamine*, $CH_2OH[CHOH]_3CH(NH_2)CHO$, m.p. 110° with decomposition (B. **31**, 2476), is obtained, with other hexosamines, by hydrolyzing with hydrochloric acid the *chitin* of the armour of lobsters, and from the cellulose of the fungus *Boletus edulis;* also from the hydrolysis of *proteïns*, particularly *mucine* (see B. **34**, 3241, etc). It is therefore of great physiological interest. It is prepared synthetically by reduction with sodium amalgam of the lactone of d-dextrosaminic acid, which is formed from d-arabinosimine, hydrocyanic, and hydrochloric acids (B. **36**, 28). It loses water with phenyl cyanate, and forms a *compound*, m.p. 211°; phenylhydrazine produces as *dextrosazone*. With hydroxylamine it forms *dextrosaminoxime*, m.p. about 122° (B. **31**, 2198). Dextrosamine reacts with nitrous acid to form an unfermentable sugar *chitose* (B. **35**, 4021; **36**, 2587); oxidation with bromine water produces d-*dextrosaminic acid* (p. 651); with nitric acid *isosaccharic acid*.

Isodextrosamine, d-*Fructosamine*, $CH_2OH[CHOH]_3CO.CHNH_2$, is obtained by reduction of dextrosazone, and when reduced by sodium amalgam yields d-mannosamine and d-glucamine (p. 624).

2B. ALDOHEPTOSES, 2C. ALDO-OCTOSES AND 2D. ALDONONOSES

(*E. Fischer*, A. **270**, 64).

Just as aldohexoses can be built up from aldopentoses, so can aldoheptoses be obtained from aldohexoses, and aldo-octoses from the aldoheptoses, etc., —*e.g.* hydrocyanic acid is added to d-mannose, the lactone of the d-mannoheptonic acid is then reduced to d-mannoheptose, which, subjected to the same reactions, yields d-manno-octose (see p. 630). The heptoses and octoses do not ferment. *Heptitols*, *octitols* and *nonitols* are formed in their reduction (p. 624).

d-**Mannoheptose,** $C_7H_{14}O_7$, m.p. 135°, is obtained (1) from the lactone of mannoheptonic acid (p. 651); (2) perseïtol yields it when oxidized (p. 625). Its *hydrazone*, m.p. about 198°, dissolves with difficulty; *osazone*, m.p. about 200° (B. **23**, 2231). Sodium amalgam converts it into perseïtol (p. 625). l-**Mannoheptose** (A. **272**, 186).

α-**Dextroheptose,** $C_7H_{14}O_7$, m.p. about 190°; *osazone*, m.p. about 195°. *β*-**Dextroheptose** (A. **270**, 72, 87).

α-**Galaheptose,** $C_7H_{14}O_7$, from *α*-galaheptonic acid, forms an *osazone*, m.p. about 200°; it is converted by hydrocyanic and hydrochloric acids into galaoctonic acid (p. 652). *β*-**Galaheptose,** m.p. with decomposition 190–194°, is obtained from the lactone of *β*-galaheptonic acid (A. **288**, 139).

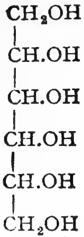
d-**Manno-octose,** $C_8H_{16}O_8$, is obtained from the lactone of manno-octonic acid (B. **23**, 2234). *α*-**Gluco-octose** (A. **270**, 95). *α*-**Galaoctose** (A. **288**, 150).

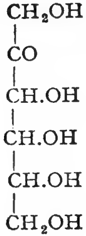
d-**Mannononose,** $C_9H_{18}O_9$, the lactone of d-mannononpremonic acid, is very similar to dextrose. *It ferments under the influence of yeast*; *hydrazone*, m.p. 223°; *osazone*, m.p. about 227° (B. **23**, 2237). **Glucononose** (A. **270**, 104).

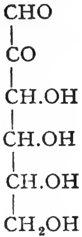
THE SYNTHESIS OF GRAPE SUGAR OR d-DEXTROSE, AND OF FRUIT SUGAR OR d-FRUCTOSE

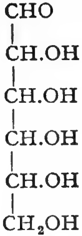
As repeatedly mentioned, *E. Fischer* succeeded in isolating *α*-**Acrose** or [d+l]-**Fructose** from the condensation products of *glycerose* (p. 534) and *formaldehyde* (p. 199). In his hands this became the parent substance for the preparation not only of lævulose or d-fructose, and of dextrose or d-glucose, but also of d-mannose, of ordinary or d-mannitol, and of ordinary or d-sorbitol, as well as of the l-modifications corresponding with the bodies just mentioned. The intimate connections between these substances are represented in a diagram given on p. 368.

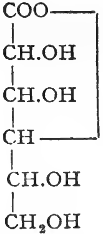
Following the course laid down in this scheme, which finally culminated in the synthesis of lævulose and of dextrose, the parent material is found to be *α-Acrose* or [d+l]-*Fructose*. This is produced by the aldol condensation of glycerose, a mixture of the first oxidation products of glycerol, through the agency of sodium hydroxide. The reduction of *α-acrose* yields *α-acritol* or [d+l]-*mannitol*, which is arrived at in the following manner: When ordinary or d-*mannitol* is oxidized, *d-mannose* results, and the latter by similar treatment becomes d-*mannonic acid*, which readily passes into its *lactone*. l-Arabinose also, by rearrangement through hydrocyanic acid, becomes l-*arabinose carboxylic acid* or l-*mannonic acid*. Its lactone combines with the lactone of d-mannonic acid and the product is the lactone of [d+l]-mannonic acid. Upon reducing the three lactones in sulphuric acid solution with sodium amalgam, d-, l-, and [d+l]-*mannose*, and [d+l]-*mannitol*, formed by the further reduction of the latter bodies, are produced. [d+l]-*Mannitol is identical with α-acritol or α-acrose.* Therefore, [d+l] mannonic acid became a very suitable parent substance in realizing the second synthesis, because *α*-acrose is very hard to obtain in anything like a desirable quantity.

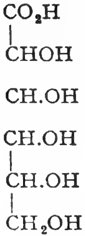

$$\begin{array}{l}CH_2OH\\|\\CH.OH\\|\\CH.OH\\|\\CH.OH\\|\\CH.OH\\|\\CH_2OH\end{array}$$
Hexitol.

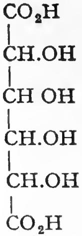

$$\begin{array}{l}CH_2OH\\|\\CO\\|\\CH.OH\\|\\CH.OH\\|\\CH.OH\\|\\CH_2OH\end{array}$$
Ketose.

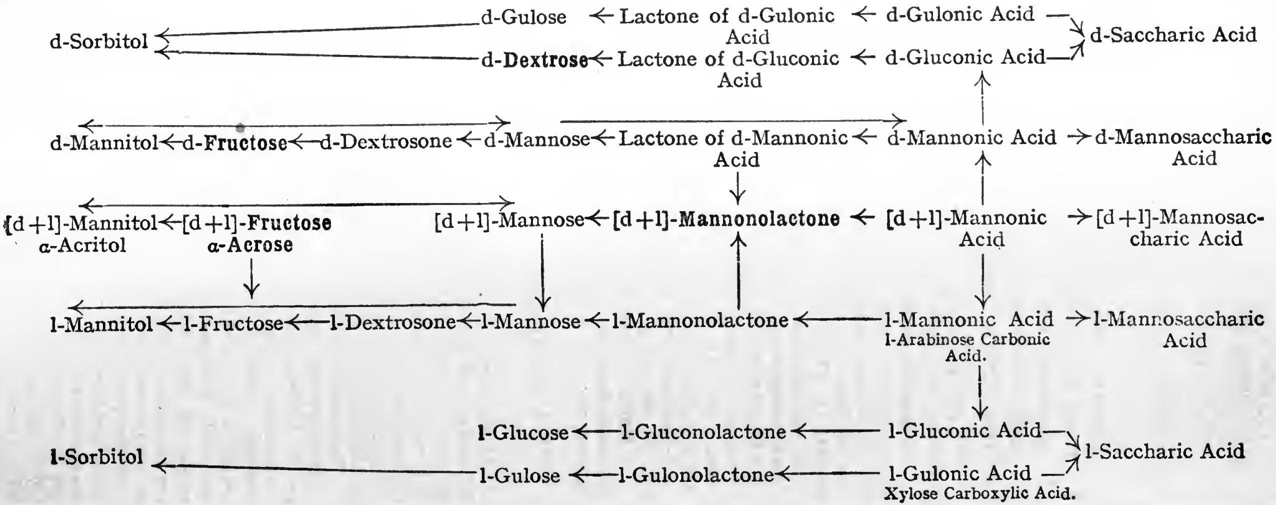

$$\begin{array}{l}CHO\\|\\CO\\|\\CH.OH\\|\\CH.OH\\|\\CH.OH\\|\\CH_2OH\end{array}$$
Osone (p. 629).


$$\begin{array}{l}CHO\\|\\CH.OH\\|\\CH.OH\\|\\CH.OH\\|\\CH.OH\\|\\CH_2OH\end{array}$$
Aldose.


Lactone of Pentahydroxy-n-caproic Acid.


$$\begin{array}{l}CO_2H\\|\\CHOH\\CH.OH\\CH.OH\\|\\CH.OH\\|\\CH_2OH\end{array}$$
Pentahydroxy-n-caproic Acid.


$$\begin{array}{l}CO_2H\\|\\CH.OH\\|\\CH\ OH\\|\\CH.OH\\|\\CH.OH\\|\\CO_2H\end{array}$$
Tetrahydroxyadipic Acid.



The course from [d+l]-mannonic acid divides in the same way to the d-derivatives as it does toward the l-compounds, because [d+l]-mannonic acid, like racemic acid (p. 601), can be resolved by strychnine and morphine into d- and l-mannonic acid. By the reduction, on the one hand, of the lactone of d-mannonic acid, d-*mannose* and d-*mannitol* are formed, and on the other hand, d-mannose and phenylhydrazine yield d-dextrosazone, which can also be obtained from dextrose or d-glucose, and lævulose or d-fructose.

d-Dextrosazone yields *dextrosone* (p. 629), and the latter by reduction forms **lævulose or d-fructose.**

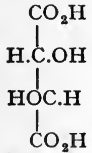
To pass d-mannonic acid to d-dextrose, the former is heated to 140° with quinoline, whereby it is then partially converted into d-*gluconic acid*. Conversely, the latter under the same conditions changes in part to d-mannonic acid (comp. the intertransformation of d-dextrose and d-mannose, by the action of alkalis, (p. 630). d-**Dextrose** or **Grape Sugar** is formed in the reduction of the lactone of d-*gluconic acid*. d-Sorbitol is produced when grape sugar is reduced. Proceeding from l-mannonic acid, the corresponding l-derivatives are similarly obtained. l-*Fructose* is also formed by the fermentation of [d+l]-fructose or *α-acrose*, and l-*mannose* in like manner from [d+l]-mannose.

The gulose groups and the sugar-acids, produced in the oxidation of the pentahydroxy-n-caproic acids, are also considered in the table. d-*Saccharic acid*, resulting from the oxidation of d-gluconic acid, becomes d-gulonic acid on reduction, and the lactone of the latter by similar treatment changes to d-*gulose*, the second aldehyde of d-sorbitol.

The aldohexoses are connected with the aldopentoses (1) through l-*arabinose*, which, by the addition of HNC, as already mentioned, passes over into arabinose carboxylic acid or l-mannonic acid, and also into l-*gluconic acid*; (2) through the *xyloses*, the HNC-addition product of which is the nitrile of *xylose carboxylic acid*, or *l-gulonic acid*. Oxidation changes l-gulonic acid to l-*saccharic* acid. l-*Gulose* and l-*sorbitol* are formed in the reduction of its lactone.

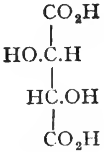
A. THE SPACE-ISOMERISM OF THE PENTITOLS AND PENTOSES, THE HEXITOLS AND HEXOSES

The structural formula of the normal, simplest pentitol: $CH_2OH.\overset{*}{C}HOH.CHOH.\overset{*}{C}HOH.CH_2OH$, contains two asymmetric carbon atoms. The CHOH-group, standing between them is the cause of two possible inactive modifications instead of one (the case with the tartaric acids), as the result of an internal compensation. Furthermore, theory permits of two optically active modifications, and a fifth optically inactive form, arising from the union of the two optically active varieties. This is the racemic or [d+l]-modification, corresponding with [d+l]-tartaric acid or racemic acid. These relations are most quickly and readily made clear by means of the atomic models. The molecule-model is projected upon the surface of the paper, and then formulæ similar to those observed with tartaric acid are derived:



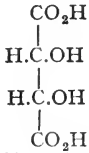
$$\begin{array}{c} CO_2H \\ | \\ H.C.OH \\ | \\ HOC.H \\ | \\ CO_2H \end{array}$$

d-Tartaric Acid.



$$\begin{array}{c} CO_2H \\ | \\ HO.C.H \\ | \\ HC.OH \\ | \\ CO_2H \end{array}$$

l-Tartaric Acid.



$$\begin{array}{c} CO_2H \\ | \\ H.C.OH \\ | \\ H.C.OH \\ | \\ CO_2H \end{array}$$

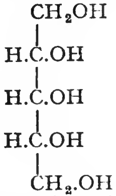
i-Tartaric Acid.

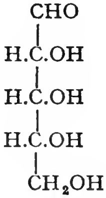
A. Space-isomerism of the Pentitols and Aldopentoses.

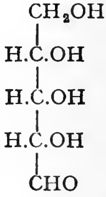
The formulæ for the four stereochemically different pentitols arise in the same manner as in the case of the tartaric acids. Suppose these four pentitols to be oxidized, in one instance the upper CH_2OH group, and then the lower similar group having been converted into the CHO-group, there will result eight stereochemically different aldopentose formulæ, none of which passes into any other by a rotation of 180°. The number of predicted space-isomers with n symmetric carbon atoms, and with an asymmetric formula may be more easily deduced by applying the 2^n formula of *van 't Hoff*, in which n indicates the number of asymmetric carbon atoms. In the aldopentoses $n=3$, hence $2^n=2^3=8$:

Pentitol (and Trihydroxyglutaric Acids).

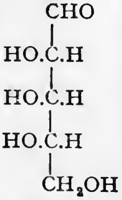
Aldopentoses (and Pentone Acids).

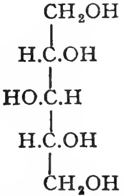
(1)

$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2.OH}\end{array}$$
Adonitol (Ribotrihydroxyglutaric Acid).

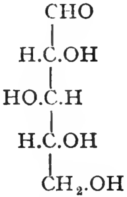
(1¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

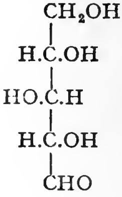

$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CHO}\end{array}$$

or

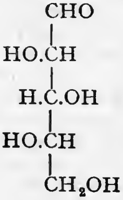
(2¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$
l-Ribose (l-Ribonic Acid).

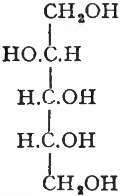
(2)

$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$
Xylitol (Xilotrihydroxyglutaric Acid).

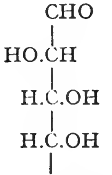
(3¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2.OH}\end{array}$$
l-Xylose (l-Xylonic Acid).

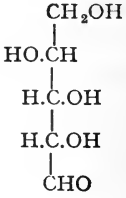

$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CHO}\end{array}$$

or

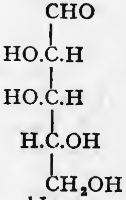
(4¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.CH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.CH}\\ |\\ \mathrm{CH_2OH}\end{array}$$
d-Xylose.

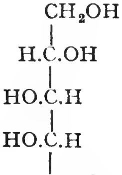
(3)

$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$
d-Arabitol (d-Trihydroxyglutaric Acid).

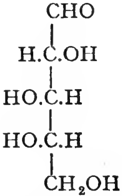
(5¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.CH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$
d-Arabinose (d-Arabonic Acid).

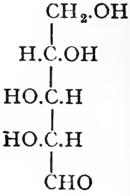

$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{HO.CH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CHO}\end{array}$$

or

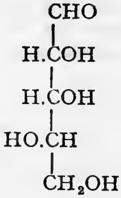
(6¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$
l-Lyxose (d-Lyxonic Acid).

(4)

$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$
l-Arabitol (l-Trihydroxyglutaric Acid).

(7¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$
l-Arabinose (l-Arabonic Acid).


$$\begin{array}{c}\mathrm{CH_2.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CHO}\end{array}$$

or

(8¹)

$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.COH}\\ |\\ \mathrm{H.COH}\\ |\\ \mathrm{HO.CH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

The stereoisomeric aldopentoses are capable naturally of uniting to four inactive double molecules, which can be resolved. The space-formulæ (7¹) and (3¹) for ordinary or l-arabinose and the xyloses follow from the intimate connection of the l-arabinoses with l-dextrose, and the xyloses with l-gulose, as will be shown later (p. 645).

If the space formula of inactive xylitol may be considered as established, there remains but one possible formula for inactive adonitol, the reduction product of ribose.

Four *trihydroxyglutaric acids* (p. 621) correspond with the four theoretically predicted pentitols. The same number of eight space isomers as indicated by the pentoses are possible also for the corresponding monocarboxylic acids, the *tetrahydroxy-n-valeric acids*, as well as for their corresponding aldehydo-carboxylic acids, and also for the *ketoses of the hexitol series*, to which fructose belongs.

B. THE SPACE-ISOMERISM OF THE SIMPLEST HEXITOLS AND THE SUGAR-ACIDS, THE ALDOHEXOSES AND THE GLUCONIC ACIDS *

The structural formula of the normal and simplest hexitol:

$CH_2OH.\overset{*4}{C}HOH.\overset{*3}{C}HOH.\overset{*2}{C}HOH.\overset{*1}{C}HOH.CH_2OH$, contains four asymmetric carbon atoms. The theory of *van 't Hoff* and *Le Bel* permits of ten possible space-isomeric configurations for such a compound.

In tartaric acid (p. 606) we started with the point of union of the two asymmetric carbon atoms in determining the successive series; and in hexitol also we begin in the middle of the molecule, and then compare C-atom 1 with C-atom 4, and C-atom 2 with C-atom 3. In this manner the ten hexitol configurations given below have been derived.

If in each of the ten hexitols, in one instance the upper —CH_2OH group, and in another the lower —CH_2OH group 2, have been oxidized to aldoses, then twenty space-isomeric aldohexoses would result. However, each of the four hexitols (Nos. 1, 2, 3, and 4) yields two aldoses, whose formulæ by a rotation of 180° pass into each other, which consequently would reduce the number of possible space-isomeric aldohexoses to 16.

Ten tetrahydroxyadipic acids (*saccharic acids*) correspond with the ten space-isomeric hexitols; sixteen pentahydroxy-n.-valeric or hexonic acids (*gluconic acids*), and sixteen aldehydotetrahydroxy-monocarboxylic acids (*glucuronic acids*) correspond with the sixteen space-isomeric aldohexoses.

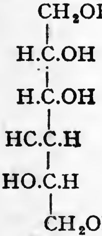
The hexitols and the tetrahydroxyadipic acids also have four inactive, racemic or [d+l]-modifications, the aldohexoses, hexonic acids, and aldehydotetrahydroxycarboxylic acids also 8 [d+l]-modifications, as is evident from an inspection of the formulæ in the appended table.

The number of theoretically possible space-isomeric aldohexoses, containing four asymmetric carbon atoms in the molecule, are more readily derived by employing the *van 't Hoff* formula 2^n given above with the aldopentoses. This for 2^4 would give sixteen space-isomeric aldohexoses.

The space-isomerism of the ketohexoses, containing three asymmetric C-atoms, has been included in the isomerism of the aldopentoses (p. 640).

Hexitols (*and Saccharic Acids*).

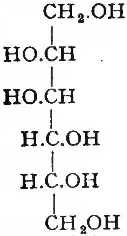
(1)



$$\begin{array}{c} CH_2OH \\ | \\ H.C.OH \\ | \\ H.C.OH \\ | \\ HC.C.H \\ | \\ HO.C.H \\ | \\ CH_2OH \end{array}$$

l-Mannitol
(l-Mannosaccharic Acid).

(2)

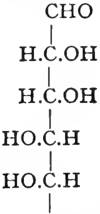


$$\begin{array}{c} CH_2.OH \\ | \\ HO.CH \\ | \\ HO.CH \\ | \\ H.C.OH \\ | \\ H.C.OH \\ | \\ CH_2OH \end{array}$$

d-Mannitol
(d-Mannosaccharic Acid).

Aldohexoses (*and Hexonic Acids*).

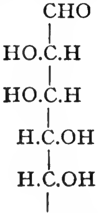
(1^1)



$$\begin{array}{c} CHO \\ | \\ H.C.OH \\ | \\ H.C.OH \\ | \\ HO.C.H \\ | \\ HO.C.H \\ | \\ CH_2OH \end{array}$$

l-Mannose
(l-Mannonic Acid).

(2^1)



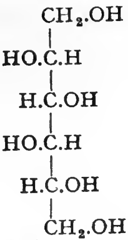
$$\begin{array}{c} CHO \\ | \\ HO.C.H \\ | \\ HO.C.H \\ | \\ H.C.OH \\ | \\ H.C.OH \\ | \\ CH_2OH \end{array}$$

d-Mannose
(d-Mannonic Acid).

---

* Die Lagerung der Atome im Raum von *J. H. van 't Hoff*, deutsch bearbeitet von *F. Herrmann* (Vieweg, Braunschweig, 1 Aufl. 1877; 2 Aufl. 1894, and Grundriss der Stereochemie von Hantzsch (Breslau, Trewendt, 1893). Lehrbuch der Stereochemie, von *A. Werner* (Fischer, Jena, 1904).

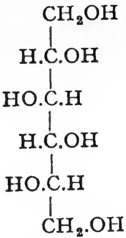
(3)



$$\begin{array}{c}\mathrm{CH_2.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2.OH}\end{array}$$

l-Iditol
(l-Idosaccharic Acid).

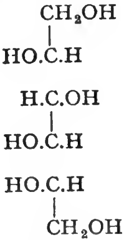
(4)



$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2.OH}\end{array}$$

d-Iditol
(d-Idosaccharic Acid).

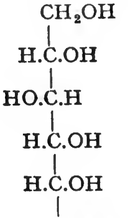
(5)



$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{HO.C.H}\\ \\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ \\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$

l-Sorbitol
(l-Saccharic Acid).

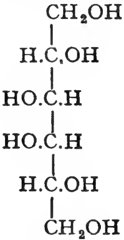
(6)



$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

d-Sorbitol
d-Saccharic Acid).

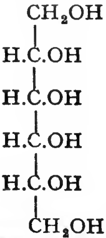
(7)



$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C,OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

Dulcitol
(Mucic Acid).

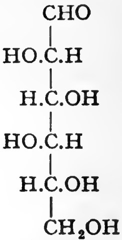
(8)



$$\begin{array}{c}\mathrm{CH_2OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

(Allomucic Acid ?).

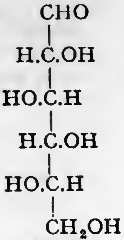
(3¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

l-Idose
(l-Idonic Acid).

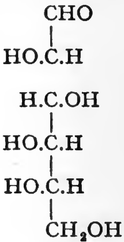
(4¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$

d-Idose
(d-Idonic Acid).

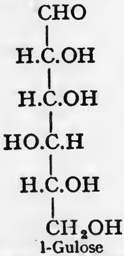
(5¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.C.H}\\ \\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$

l-Dextrose
(l-Gluconic Acid).

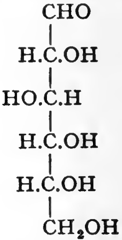
(6¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

l-Gulose
l-Gulonic Acid).

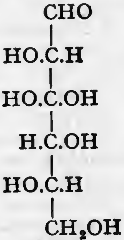
(7¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

d-Dextrose
(d-Gluconic Acid).

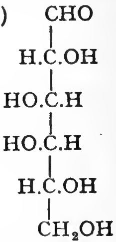
(8¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$

d-Gulose
(d-Gulonic Acid).

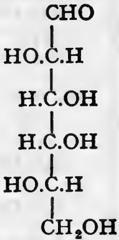
(9¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

d-Galactose
(d-Galactonic Acid)

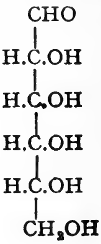
(10¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$

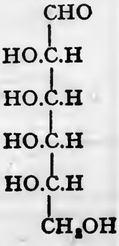
l-Galactose
(l-Galactonic Acid).

(11¹)



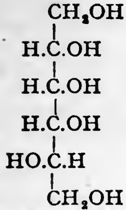
$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{H.C.OH}\\ |\\ \mathrm{CH_2OH}\end{array}$$

(12¹)



$$\begin{array}{c}\mathrm{CHO}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{HO.C.H}\\ |\\ \mathrm{CH_2OH}\end{array}$$

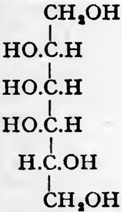
(9)



$$\begin{array}{c} CH_2OH \\ \vert \\ H.C.OH \\ \vert \\ H.C.OH \\ \vert \\ H.C.OH \\ \vert \\ HO.C.H \\ \vert \\ CH_2OH \end{array}$$

(l-Talomucic Acid).

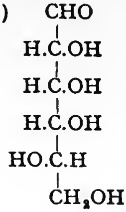
(10)



$$\begin{array}{c} CH_2OH \\ \vert \\ HO.C.H \\ \vert \\ HO.C.H \\ \vert \\ HO.C.H \\ \vert \\ H.C.OH \\ \vert \\ CH_2OH \end{array}$$

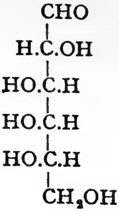
d-Talitol (d-Talomucic Acid).

(13^1)



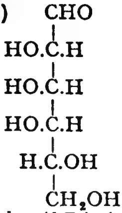
$$\begin{array}{c} CHO \\ \vert \\ H.C.OH \\ \vert \\ H.C.OH \\ \vert \\ H.C.OH \\ \vert \\ HO.C.H \\ \vert \\ CH_2OH \end{array}$$

(14^1)



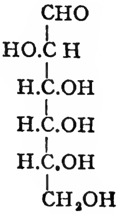
$$\begin{array}{c} CHO \\ \vert \\ H.C.OH \\ \vert \\ HO.C.H \\ \vert \\ HO.C.H \\ \vert \\ HO.C.H \\ \vert \\ CH_2OH \end{array}$$

(15^1)



$$\begin{array}{c} CHO \\ \vert \\ HO.C.H \\ \vert \\ HO.C.H \\ \vert \\ HO.C.H \\ \vert \\ H.C.OH \\ \vert \\ CH_2OH \end{array}$$

(16^1)



$$\begin{array}{c} CHO \\ \vert \\ HO.C\ H \\ \vert \\ H.C.OH \\ \vert \\ H.C.OH \\ \vert \\ H.C.OH \\ \vert \\ CH_2OH \end{array}$$

d-Talose (d-Talonic Acid).

To render rational names possible, *E. Fischer* has proposed to indicate the configuration by the sign + or —. These are not intended to show the influence of the individual asymmetric carbon atom upon the optical properties of the molecule, as *van 't Hoff* formerly expressed it, but merely the position of a substituent upon the right or left side of the preceding configuration formulæ. (See also B. **40**, 102.) The formula should be so viewed that in the sugars the aldehyde or ketone group, and in the monobasic acids the carboxyls stand above. The numbers begin above, and the sign + or — represents the position of hydroxyl, *e.g.*:

Grape Sugar, **d-Dextrose** = Hexanepentolal + — + + (Formula 7^1).
d-Gluconic Acid . = Hexanepentol acid + — + + (Formula 7^1).
Lævulose, **d-Fructose** = Hexanepentol-2-one — + +.

"In the case of symmetrical structure,—as it exists, for example, in the diacids and alcohols of the sugar group,—there is no favoured position; consequently, presuming that the numbering invariably proceeds from the top down, we get a doubled steric designation," *e.g.*:

d-Saccharic Acid . . = Hexanetetrol diacid + — + + or — — + —
Dulcitol . . . . . = Hexanehexol . + — — + or — + + —

Derivation of the Space-formula for d-Dextrose or Grape Sugar, the most important aldohexose. The following relations arranged first in the diagram are the basis of this derivation:

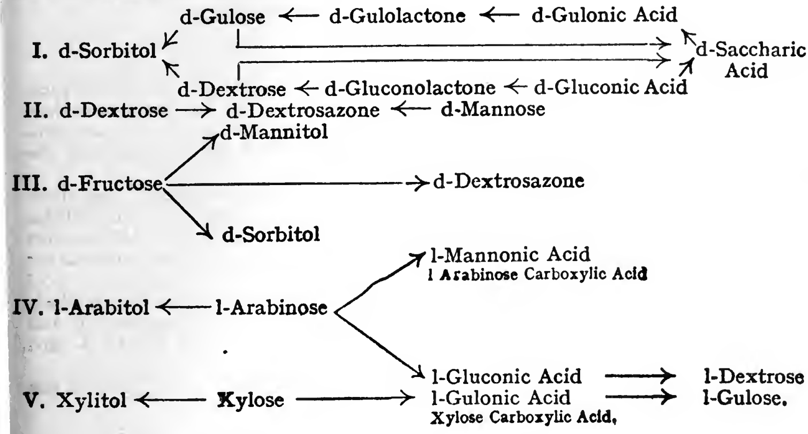
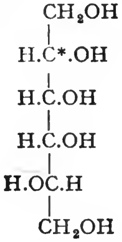


Diagram I shows that d-dextrose or grape sugar and d-gulose yield the same d-saccharic acid. Hence it follows that d-saccharic acid and the d-sorbitol corresponding with it cannot have the formulæ (1), (2), (3), (4) (p. 641), because it is only the hexitols and saccharic acids, (5), (6), (7), (8), (9), (10), which yield two space-isomeric aldohexoses each. The formulæ (7) and (8) of the six space-formulæ represent, by virtue of internal compensation, optically inactive molecules, which therefore disappear for the optically active d-saccharic acid and d-sorbitol.

The fact that d-saccharic acid and d-mannosaccharic acid, d-gluconic and d-mannonic acids, d-dextrose and d-mannose, d-sorbitol and d-mannitol, only differ by the varying arrangement of the univalent atoms or atomic groups with reference to the carbon atom, which in d-dextrose and d-mannose is linked to the aldehydo-group, makes it possible to decide between the stereoisomeric formulæ (5) and (6), (9) and (10); for d- and l-saccharic acid, d-mannose and d-dextrose, yield the same osazone. diagram II (p. 643). l-Arabinose treated with hydrocyanic and hydrochloric acids gives rise to both l-mannonic or l-arabinose carboxylic acid, and l-gluconic acid (diagram IV, p. 643). The same relations which are observed with l-mannonic and l-gluconic acid prevail naturally with their stereoisomers—d-mannonic acid and d-gluconic acid. A mixture of d-mannitol and d-sorbitol is obtained by the reduction of d-fructose.

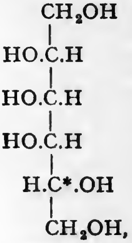
Assuming that d-sorbitol and d-saccharic acid possessed the space-formulæ (9) or (10) (p. 643):

(9)



$$\begin{array}{c} CH_2OH \\ | \\ H.C^*.OH \\ | \\ H.C.OH \\ | \\ H.C.OH \\ | \\ H.OC.H \\ | \\ CH_2OH \end{array}$$

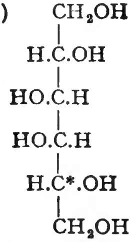
(10)



$$\begin{array}{c} CH_2OH \\ | \\ HO.C.H \\ | \\ HO.C.H \\ | \\ HO.C.H \\ | \\ H.C^*.OH \\ | \\ CH_2OH, \end{array}$$

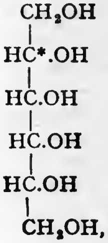
then d-mannitol, and also d-mannosaccharic acid, would have the formulæ (7) or (8):

(7)



$$\begin{array}{c} CH_2OH \\ | \\ H.C.OH \\ | \\ HO.C.H \\ | \\ HO.C.H \\ | \\ H.C^*.OH \\ | \\ CH_2OH \end{array}$$

(8)

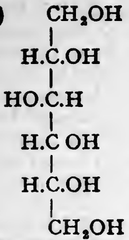


$$\begin{array}{c} CH_2OH \\ | \\ HC^*.OH \\ | \\ HC.OH \\ | \\ HC.OH \\ | \\ HC.OH \\ | \\ CH_2OH, \end{array}$$

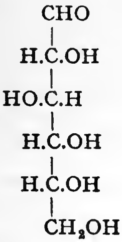
because only these formulæ differ from (9) and (10) *exclusively* in the varying arrangement of the atoms or atom groups with reference to asymmetric carbon atoms, designated by asterisks. However, formulæ (7) and (8) by internal compensation give rise to inactive molecules, consequently cannot give back the configuration of d-mannitol and d-mannosaccharic acid.

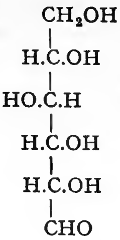
Thus, for d-sorbitol and l-sorbitol, d-saccharic acid and l-saccharic acid there remain only formulæ (5) and (6), from which (6) is arbitrarily selected for d-sorbitol and d-saccharic acid, and (5) for l-sorbitol and l-saccharic acid. "When this has been done then all further arbitrary selection ceases; now the formulæ for all optically active compounds connected experimentally with saccharic acid are regarded as established" (B. 27, 3217). Hence, the space-formula (2) falls to d-mannitol and d-mannosaccharic acid, and formula (1) to l-mannitol and l-mannosaccharic acid, which would also give formulæ (2) and (1^1) to d- and l-mannonic acids (p. 648).

The aldohexoses (7^1) and (8^1) (p. 642) correspond with d-sorbitol and the saccharic acid with space-formula (6):

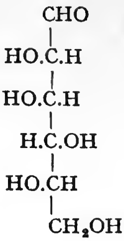
(6)

$$\begin{array}{c}CH_2OH\\|\\H.C.OH\\|\\HO.C.H\\|\\H.C.OH\\|\\H.C.OH\\|\\CH_2OH\end{array}$$

d-Sorbitol (d-Saccharic Acid).

(7^1)

$$\begin{array}{c}CHO\\|\\H.C.OH\\|\\HO.C.H\\|\\H.C.OH\\|\\H.C.OH\\|\\CH_2OH\end{array}$$

$(\underline{8}^1)$

$$\begin{array}{c}CH_2OH\\|\\H.C.OH\\|\\HO.C.H\\|\\H.C.OH\\|\\H.C.OH\\|\\CHO\end{array}$$

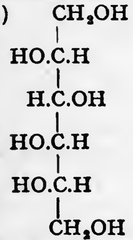
or when rotated 180°

(8^1)

$$\begin{array}{c}CHO\\|\\HO.C.H\\|\\HO.C.H\\|\\H.C.OH\\|\\HO.CH\\|\\CH_2OH\end{array}$$

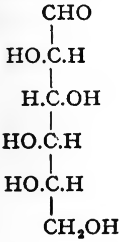
In order to obtain the aldehyde group at the top of the formula image, formula $(\underline{8}^1)$ must be turned 180°. This converts it into formula (8^1), and the succession of the atomic groups attached to the asymmetric carbon atom is naturally not altered.

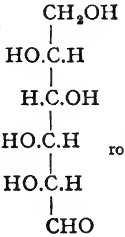
The choice between formulæ (7^1) and (8^1) for d-dextrose and d-gulose still remains. We are able to determine this if we can select out the space-formulæ for the two stereoisomers—l-dextrose and l-gulose. This is possible with a proper consideration of the genetic relation of the last two bodies with l-arabinose and xylose, as represented in diagrams IV and V (p. 643).

The formulæ (5^1) and $(\underline{6}^1)$ of the aldohexoses correspond with the formula (5) of l-saccharic acid. $(\underline{6}^1)$ when rotated becomes (6^1):

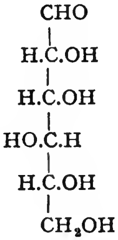
(5)

$$\begin{array}{c}CH_2OH\\|\\HO.C.H\\|\\H.C.OH\\|\\HO.C.H\\|\\HO.C.H\\|\\CH_2OH\end{array}$$

l-Sorbitol (l-Saccharic Acid).

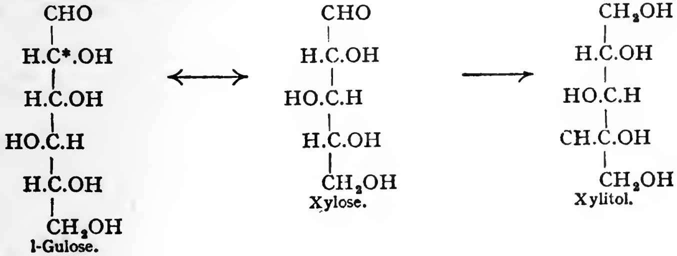
(5^1)

$$\begin{array}{c}CHO\\|\\HO.C.H\\|\\H.C.OH\\|\\HO.C.H\\|\\HO.C.H\\|\\CH_2OH\end{array}$$

$(\underline{6}^1)$

$$\begin{array}{c}CH_2OH\\|\\HO.C.H\\|\\H.C.OH\\|\\HO.C.H\\|\\HO.C.H\\|\\CHO\end{array}$$

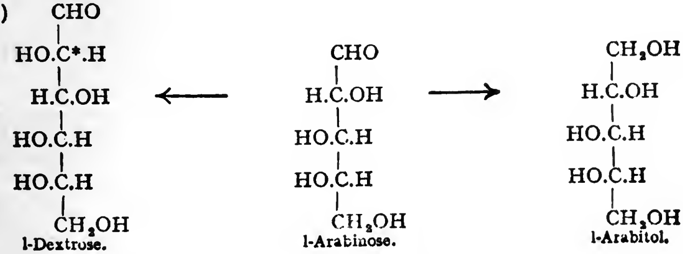
or when rotated 180°

(6^1)

$$\begin{array}{c}CHO\\|\\H.C.OH\\|\\H.C.OH\\|\\HO.C.H\\|\\H.C.OH\\|\\CH_2OH\end{array}$$

Remembering that, according to diagram IV (p. 643), it is possible to obtain d-dextrose from l-arabinose, and, according to diagram V, l-gulose from xylose, then the pentoses mentioned must have the space-formulæ which can be derived for formulæ (5^1) and (6^1) by omitting the first of the C*-atoms, by which the structure becomes asymmetric:

(6^1)

$$\begin{array}{c}CHO\\|\\H.C^*.OH\\|\\H.C.OH\\|\\HO.C.H\\|\\H.C.OH\\|\\CH_2OH\end{array}\longleftrightarrow\begin{array}{c}CHO\\|\\H.C.OH\\|\\HO.C.H\\|\\H.C.OH\\|\\CH_2OH\end{array}\longrightarrow\begin{array}{c}CH_2OH\\|\\H.C.OH\\|\\HO.C.H\\|\\CH.C.OH\\|\\CH_2OH\end{array}$$

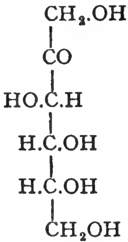
l-Gulose. Xylose. Xylitol.

(5^1)

$$\begin{array}{c}CHO\\|\\HO.C^*.H\\|\\H.C.OH\\|\\HO.C.H\\|\\HO.C.H\\|\\CH_2OH\end{array}\longleftarrow\begin{array}{c}CHO\\|\\H.C.OH\\|\\HO.C.H\\|\\HO.C.H\\|\\CH_2OH\end{array}\longrightarrow\begin{array}{c}CH_2OH\\|\\H.C.OH\\|\\HO.C.H\\|\\HO.C.H\\|\\CH_2OH\end{array}$$

l-Dextrose. l-Arabinose. l-Arabitol.

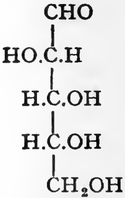
It is at once seen that the aldopentose corresponding with formula (6^1) must, by reduction, yield an inactive pentitol, *xylitol* (p. 616)—through an internal compensation. Similarly, the pentose with formula (5^1) changes to an optically active pentitol—l-*arabitol* (p. 616). In this manner is fixed not only the configuration for xylitol and xylose, l-arabitol and l-arabinose, but it is also demonstrated that l-gulose, from xylose, has the formula (6^1), and l-dextrose, synthesized from l-arabinose, the space-formula (5^1). (8^1) is the stereoisomeric formula of space-formula (6^1), which, therefore, belongs to d-*gulose*. Formula (7^1) corresponds with space-formula (5^1), and hence it belongs to d-*dextrose*. From all this it would follow that d- and l-mannoses have formulæ (2^1) and (1^1), which facts confirm that d-dextrose and d-mannose on the one hand, and l-dextrose and l-mannose on the other, pass into the same dextrosazone—*i.e.* they differ only in the configuration at *one* asymmetric C-atom.

When it is remembered that d-fructose, by reduction, yields a mixture of d-mannitol and d-sorbitol, and d-dextrosazone on treatment with phenylhydrazine, it will be recognized that both it and its corresponding d-arabinose must have the space-formulæ:



$$\begin{array}{c}\mathrm{CH_2.OH}\\|\\\mathrm{CO}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{CH_2OH}\end{array}$$

d-Fructose.



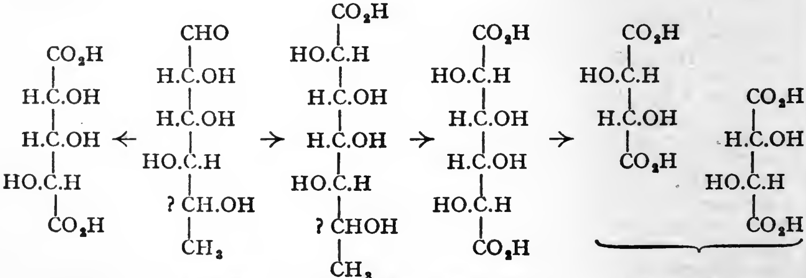
$$\begin{array}{c}\mathrm{CHO}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{CH_2OH}\end{array}$$

d-Arabinose.

The configurations of other ketoses, such as *tagatose* and *sorbose* (p. 636), can similarly be derived.

DERIVATION OF THE CONFIGURATION OF d-TARTARIC ACID

The configuration of d-tartaric acid is evident, according to *E. Fischer*, from its production in the oxidation of d-saccharic acid. The formula of the latter has been previously deduced above. It is in harmony, therefore, with its formation in the oxidation of methyl tetrose (p. 597), a decomposition product of rhamnose. The latter, when oxidized, passes into l-trihydroxyglutaric acid. The α-rhamnohexonic acid, obtained from the latter by the hydrocyanic acid addition, yields mucic acid on oxidation, and the latter, on similar treatment, changes to racemic acid. Assuming that the methyl group of rhamnose is eliminated in the oxidation of rhamnohexonic acid, rhamnose would have the following configuration-formula:



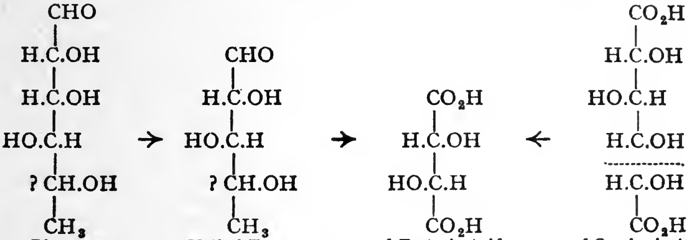
$$\begin{array}{c}\mathrm{CO_2H}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{CO_2H}\end{array} \leftarrow \begin{array}{c}\mathrm{CHO}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{HO.C.H}\\|\\?\ \mathrm{CH.OH}\\|\\\mathrm{CH_3}\end{array} \rightarrow \begin{array}{c}\mathrm{CO_2H}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{HO.C.H}\\|\\?\ \mathrm{CHOH}\\|\\\mathrm{CH_3}\end{array} \rightarrow \begin{array}{c}\mathrm{CO_2H}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{CO_2H}\end{array} \rightarrow \underbrace{\begin{array}{c}\mathrm{CO_2H}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{CO_2H}\end{array} \quad \begin{array}{c}\mathrm{CO_2H}\\|\\\mathrm{H.C.OH}\\|\\\mathrm{HO.C.H}\\|\\\mathrm{CO_2H}\end{array}}$$

l-Trihydroxy-glutaric Acid. Rhamnose. α-Rhamnose Carboxylic Acid. Mucic Acid. Racemic Acid.

This assumption has been proved through the behaviour of the stereoisomeric β-rhamnohexonic acid, which results on heating α-rhamnohexonic acid to 140°

with pyridine. All experiences go to show that the two stereoisomeric rhamnohexonic acids only differ in the arrangement or position of the carboxyl group in direct union with the asymmetric carbon atom. Had the methyl group not been split off in the oxidation, but merely changed to carboxyl, then α- and β-rhamnohexonic acids would have yielded the same mucic acid, because the asymmetric C-atom linked to carboxyl in α- and β-rhamnohexonic acid, that caused the difference in the two acids, would have been oxidized to carboxyl. β-Rhamnohexonic acid, however, oxidizes to l-talomucic acid, which justifies the preceding assumption, and consequently proves the configuration, even to the position of the asymmetric carbon atom linked to methyl.

Wohl's procedure permits of the conversion of rhamnose into methyl tetrose, which is oxidized to d-tartaric acid by nitric acid. Hence, we may suppose that here the methyl group is split off as in the case of the oxidation of rhamnose to l-trihydroxyglutaric acid, and of α-rhamnohexonic acid to mucic acid. This then demonstrates the configuration of d-tartaric acid (B. **29**, 1377):



$$\begin{array}{c}\text{CHO}\\|\\\text{H.C.OH}\\|\\\text{H.C.OH}\\|\\\text{HO.C.H}\\|\\\text{? CH.OH}\\|\\\text{CH}_3\end{array}\rightarrow\begin{array}{c}\text{CHO}\\|\\\text{H.C.OH}\\|\\\text{HO.C.H}\\|\\\text{? CH.OH}\\|\\\text{CH}_3\end{array}\rightarrow\begin{array}{c}\text{CO}_2\text{H}\\|\\\text{H.C.OH}\\|\\\text{HO.C.H}\\|\\\text{CO}_2\text{H}\end{array}\leftarrow\begin{array}{c}\text{CO}_2\text{H}\\|\\\text{H.C.OH}\\|\\\text{HO.C.H}\\|\\\text{H.C.OH}\\\cdots\cdots\\\text{H.C.OH}\\|\\\text{CO}_2\text{H}\end{array}$$

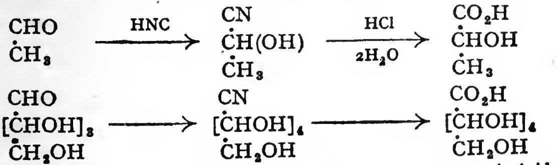
Rhamnose. **Methyl Tetrose.** **d-Tartaric Acid.** **d-Saccharic Acid.**

4. **Hexaketones.** *Oxalyl Bis-acetyl Acetone*, $(CH_3CO)_2CHCO.CO.CH(COCH_3)_2$, is the parent substance of *dicyano*-bis-*acetyl acetone*, *αα₁-Tetracetyl ββ₁-Diiminobutane*, $(CH_3CO)CHC(NH).C(NH).CH(COCH_3)_2$, m.p. 147°, which is prepared from dicyanomonacetyl acetone (p. 599), acetyl acetone, and a little alcoholate. Even when boiled in water it is changed into a *carbocyclic* derivative (A. **332**, 146).

5. POLYHYDROXYMONOCARBOXYLIC ACIDS

A. PENTAHYDROXYCARBOXYLIC ACIDS

These acids are produced (1) by the oxidation of the alcohols and aldoses corresponding with them (B. **32**, 2273), by means of chlorine and bromine water; (2) by the reduction of the corresponding aldehydo-acids and lactones of dicarboxylic acids; synthetically, from the aldopentoses (arabinose, rhamnose, p. 618) by means of HNC, etc. This is analogous to the synthesis of glycollic acid from formaldehyde, and ethylidene lactic acid from acetaldehyde:



$$\begin{array}{c}\text{CHO}\\\dot{\text{C}}\text{H}_3\end{array}\xrightarrow{\text{HNC}}\begin{array}{c}\text{CN}\\\dot{\text{C}}\text{H(OH)}\\\dot{\text{C}}\text{H}_3\end{array}\xrightarrow[2\text{H}_2\text{O}]{\text{HCl}}\begin{array}{c}\text{CO}_2\text{H}\\\dot{\text{C}}\text{HOH}\\\dot{\text{C}}\text{H}_3\end{array}$$

$$\begin{array}{c}\text{CHO}\\{[\dot{\text{C}}\text{HOH}]_3}\\\dot{\text{C}}\text{H}_2\text{OH}\end{array}\longrightarrow\begin{array}{c}\text{CN}\\{[\dot{\text{C}}\text{HOH}]_4}\\\dot{\text{C}}\text{H}_2\text{OH}\end{array}\longrightarrow\begin{array}{c}\text{CO}_2\text{H}\\{[\dot{\text{C}}\text{HOH}]_4}\\\dot{\text{C}}\text{H}_2\text{OH}\end{array}$$

l-Arabinose. **l-Gluconitrile.** **l-Gluconic Acid. l-Arabinose Carboxylic Acid.**

Behaviour.—(1) Being γ- and δ-hydroxy-derivatives, nearly all of these acids are very unstable when in a free condition. They lose water readily and pass into *lactones* (p. 371):

$$C_6H_{12}O_7 \xrightarrow{-H_2O} C_6H_{10}O_6.$$

(2) The capacity of the lactones, but not the acids themselves, to pass into the corresponding aldohexoses by combination with two atoms of hydrogen (*E. Fischer*), is of great importance in the synthesis of the aldoses (p. 625):

$$\underset{\text{d-Gluconolactone.}}{C_6H_{10}O_6} \xrightarrow{2H} \underset{\text{d-Dextrose.}}{C_6H_{12}O_6.}$$

(3) These acids, when acted on with phenylhydrazine, form characteristic crystalline *phenylhydrazides*, $C_5H_{11}O_5.CO.N_2H_2C_6H_5$ (B. **22**, 2728). They are decomposed into their components when boiled with alkalis. They are distinguished from the hydrazones of the aldehydes and ketones by the *reddish-violet* coloration produced upon mixing them with concentrated sulphuric acid and a drop of ferric chloride.

(4) Heated to 130–150° with quinoline or pyridine a geometric rearrangement ensues, which, is, however, restricted to the asymmetric carbon atom in union with the carboxyl (comp. the inter-transformation of stereomeric hexoses under the influence of alkali, p. 630). It is a reversible reaction, and therefore yields a mixture of both stereoisomers, *e.g.* (B. **27**, 3193):

d- and l-Gluconic Acid $\longleftrightarrow$ d- and l-Mannonic Acid.
l-Gulonic Acid $\longleftrightarrow$ l-Idonic Acid.
d-Galactonic Acid $\longleftrightarrow$ d-Talonic Acid.

(5) These acids are reduced to lactones of the γ-monohydroxy-carboxylic acids (p. 374), if they are heated with hydriodic acid.

(6) Oxidation of the hexonic acids or their lactones with hydrogen peroxide and ferric acetate, causes degradation to the pentoses (comp. p. 616).

Isomerism.—Spacial isomers of pentahydroxy-n.-caproic acid are as numerous, according to theory, as the aldohexoses (p. 641), *i.e.* sixteen optically active and eight [d+l]-modifications, which are inactive.

Mannonic Acid, $C_5H_6(OH)_5.CO_2H$. The syrup-like acids—d-, l-, and [d+l]-mannonic acids—yield d-, l-, and [d+l]-*mannosaccharic acids* on oxidation (p. 653). They change to lactones on the evaporation of their solutions; which by further reduction yield d-*mannitol*, l-*mannitol*, and [d+l]-*mannitol*. [d+l]-*Mannitol is identical with α-acritol, the reduction product of synthetic α-acrose* or [d+l]-fructose. As [d+l]-*mannitol* or α-acritol, when oxidized, yields [d+l]-mannose, and the latter by similar treatment becomes converted into [d+l]-mannonic acid, which can be split into d-mannonic acid and l-mannonic acid, the complete synthesis of all bodies of the mannitol series can be realized through these reactions (p. 637):

$$\begin{tikzcd}
& \text{d-Mannitol} & \text{d-Mannose} \arrow[l] & \text{d-Mannonolactone} \arrow[l] & \\
& & & \text{d-Mannonic Acid} \arrow[u] \arrow[r] & \text{d-Mannosaccharic Acid} \\
\alpha\text{-Acrose} \arrow[r] & \alpha\text{-Acritol} & \text{[d+l] Mannose} \arrow[l] & \text{[d+l]-Mannonic Acid} \arrow[l] \arrow[r] & \text{[d+l]-Mannosaccharic Acid} \\
\text{[d+l]-Fructose} & \text{[d+l]-Mannitol} & & \text{l-Mannonic Acid} \arrow[r] \arrow[d] & \text{l-Mannosaccharic Acid} \\
& \text{l-Mannitol} & \text{l-Mannose} \arrow[l] & \text{l-Mannonolactone.} \arrow[l] &
\end{tikzcd}$$

d-Mannonolactone, $C_6H_{10}O_6$, m.p. 149–153° $[\alpha]_D = +53.8°$
l-Mannonolactone, " 140–150° $[\alpha]_D = +54.8°$
[d+l]-Mannonolactone $(C_6H_{10}O_6)_2$, m.p. 149–155°.

d- and l-*Mannonic Acid Phenylhydrazide*, $C_6H_{11}O_6(N_2H_2.C_6H_5)$, m.p. 215°.

[d+l]-*Mannonic Acid Phenylhydrazide*, m.p. about 230° when it is rapidly heated. The hydrazides are converted into the acids on boiling with barium hydroxide solution (B. **22,** 3221), a reaction which is well adapted for the purification of the acids. d- and l-*Methylene Mannonic Lactone*, $(C_6H_8O_6(CH_2)$, m.p. 206° (A. **310,** 181).

A very important feature is that *a partial conversion of d- and l-mannonic acid into d- and l- gluconic acids occurs on heating the former to* 140° *with quinoline.* The last two acids, subjected to the same treatment, change in part into d- and l-mannonic acids.

This method of preparing d- and l-gluconic acids shows the genetic connection existing between d- and l-dextrose and the mannitol series, and thereby renders possible the synthesis of dextrose.

The formation of l-mannonic acid or l-arabinose carboxylic acid (together with l-gluconic acid) from l-arabinose by means of hydrocyanic acid, constitutes one of the transitions which allows of the synthesis of aldohexoses from aldopentoses:

$$\text{l-Arabinose}\begin{cases}\text{l-Mannonic Acid} \longrightarrow \text{l-Mannonolactone} \longrightarrow \text{l-Mannose}\\ \text{l-Arabinose Carboxylic Acid.}\\ \text{l-Gluconic Acid} \longrightarrow \text{l-Gluconolactone} \longrightarrow \text{l-Dextrose.}\end{cases}$$

Gluconic Acid, $CH_2OH[CHOH]_4CO_2H$, is known in the d-, l-, and [d+l]-modifications (B. **23,** 801, 2624; **24,** 1840) (space formula, see p. 642).

1. The lactones of these three acids change to d-, l-, and [d+l]-dextrose on reduction.

2. By oxidation they become converted into d-, l-, and [d+l]-saccharic acids.

3. When heated to 140° with quinoline they change in part to d-, l-, and [d+l]-mannonic acids (p. 648). Conversely, d-, l-, and [d+l]-gluconic acids are obtained by the same treatment from d-, l-, and [d+l]-mannonic acids.

The d- and l-*phenylhydrazides*, $C_6H_{11}O_6(N_2H_2.C_6H_5)$, m.p. about 200° when they are rapidly heated; [d+l]-*phenylhydrazide*, m.p. 190°.

d-Gluconic Acid, *Dextronic Acid, Maltonic Acid*, is formed (1) by the oxidation of dextrose, sucrose, dextrin, starch, and maltose with chlorine or bromine water; and is most readily obtained from dextrose (B. **17,** 1298); (2) from d-mannonic acid. Gluconic acid forms a syrup which, when evaporated or upon standing, changes in part to its crystalline lactone, $C_6H_{10}O_6$, m.p. 130–135°. Sodium amalgam reduces it to d-*dextrose* or *grape sugar* (B. **23,** 804). Its *barium* salt crystallizes with three molecules of water; *calcium salt* with one. The acid is dextro-rotatory. On the conversion into d-arabinose by oxidation with H_2O_2, see p. 618.

Pentacetyl Glucononitrile, $C_5H_6(O.C_2H_3O)_5CN$ (B. **26,** 730). *Dimethylene Gluconic Acid*, $C_6H_8O_7(:CH_2)_2$, m.p. 220°, is prepared from d-gluconic acid and formaldehyde (A. **292,** 31; **310,** 181).

l-Gluconic acid is formed (1) from l-mannonic acid (p. 648) and (2) together with l-mannonic acid from l-arabinose by aid of HNC.

[d+l]-Gluconic Acid is obtained from a mixture of d- and l-gluconic acids. Its *calcium* salt, which dissolves with difficulty, is obtained, like calcium racemate, by mixing solutions of d- and l-calcium gluconates.

Gulonic Acid, $CH_2OH[CHOH]_4CO_2H$, is known in three forms, which become converted into d-, l-, and d+l]-saccharic acids (p. 653) when they are oxidized. The reduction of their lactones produces d-, l-, and [d+l]-*guloses* (p. 635).

d-Gulonic Acid is obtained by reduction both of glucuronic acid (p. 752) and d-saccharic acid; *lactone*, m.p. 181°; *phenylhydrazide*, m.p. 148° (B. **24**, 526).

l-Gulonic Acid, *Xylose Carboxylic Acid*, results when xylose is acted on with HNC. This reaction unites also the aldopentoses with the aldohexoses. l-Idonic acid is produced simultaneously, and when heated with pyridine changes partially to l-gulonic acid. l-*Gulonic Lactone*, m.p. 185°, yields l-xylose when oxidized with H_2O_2 (p. 619); *phenylhydrazide*, m.p. 147–149° (B. **23**, 2628); **24**, 528).

[d+l]-Gulonic Acid readily changes into its lactone, which by crystallization splits into d- and l-gulonolactone. Calcium [d+l]-gulonate dissolves with more difficulty than calcium d- and l-gulonate; *phenylhydrazide*, m.p. 153–155° (B. **25**, 1025).

l-Idonic Acid is formed together with l-gulonic acid from xylose, and is separated by means of its brucine salt from the mother liquor of l-gulonolactone. Heated with pyridine to 140°, it changes in part to l-gulonic acid, and *vice versâ*. l-Idose is its reduction product (p. 635). d-*Idonic Acid*, obtained from d-gulonic acid by means of pyridine, yields d-idose on reduction (B. **28**, 1975).

Galactonic Acid, $CH_2OH[CHOH]_4CO_2H$, is known in three modifications, [d+l]-*Galactonic Acid* results in the reduction of ethyl mucic ester and also of the lactone of mucic acid; [d+l]-*lactone*, m.p. 122–125°; *phenylhydrazide*, m.p. 205°. This acid can be resolved by means of its strychnine salt into the l-salt, which is more easily soluble in alcohol, and the d-salt, which dissolves with more difficulty (B. **25**, 1256). l-*Galactonic Acid* resembles in a remarkable degree the longer-known—

d-Galactonic Acid, *Lactonic Acid*, $CH_2OH[CHOH]_4CO_2H$, which is produced from lactose, d-galactose, and gum arabic by the action of bromine water; also, with d-talonic acid, from d-lyxose cyanhydrin by hydrolysis (B. **33**, 2146). It can be converted into d-talonic acid, and then be prepared from the latter. It is converted into mucic acid by oxidation with nitric acid (p. 654). It crystallizes, and at 100°, yields d-*galactonic lactone*, $C_6H_{10}O_6$, m.p. 91°, which unites with water of crystallization to form $C_6H_{10}O_6+H_2O$, m.p. 64° (A. **271**, 83). Acetyl chloride produces *Triacetyl Galactonic Lactone Chlorhydrin*, $C_6H_6O_2(OCOCH_3)_3Cl$, m.p. 98° (B. **35**, 943). Reduction converts it into the lactone d-galactose (p. 635); *calcium salt*, $(C_6H_{11}O_7)_2Ca+5H_2O$; *phenylhydrazide*, m.p. 200–205°; *amide*, m.p. 175°; *anilide*, m.p. 210° (B. **28**, R. 606).

Dimethylene Galactonic Acid, $C_5H_7O_5(CH_2)_2CO_2H$, m.p. 136 (A. **310**, 181). *Pentacetyl* d-*Galactonic Nitrile*, b.p. 135°, is formed from d-galactose oxime and acetic anhydride, and yields, with silver oxide and ammonia, the acetamide compound of lyxose (p. 619).

d-Talonic Acid, $CH_2OH[CHOH]_4CO_2H$, results together with hydroxymethylene pyromucic acid on heating d-galactonic acid with pyridine or quinoline to 140–150°. Conversely, d-galactonic acid is obtained from d-talonic acid by the same treatment (B. **27**, 1526). Reduction changes it to d-talose (p. 635).

α-Rhamnose Carboxylic Acid, $CH_3[CHOH]_5CO_2H$, is formed from rhamnose (see Isodulcitol, p. 619) with HNC, etc.; *lactone*, $C_7H_{12}O_6$, m.p. 162–168° (B. **21**, 2173); *phenylhydrazide*, $C_7H_{13}O_6.N_2H_2C_6H_5$, m.p. about 210° (B. **22**, 2733). When heated with hydrochloric acid and phosphorus it is reduced to n-heptylic acid, $C_7H_{14}O_2$; but sodium amalgam changes it into the lactone of *methyl hexose* (p. 635) (B. **23**, 936). Oxidation produces mucic acid (B. **27**, 384).

β-Rhamnose Carboxylic Acid is formed when the α-compound is heated to 150–155° with pyridine; *lactone*, m.p. 134–138°; *phenylhydrazide*, m.p. 170°. Oxidation converts the β-acid into l-talomucic acid (p. 654). *Chitonic Acid*, which is produced from *chitose* (p. 636) and bromine water, and *chitaric acid*, $C_6H_{10}O_6$, prepared from d-glucaminic acid (see above) and nitrous acid are probably stereomeric *trihydroxymethyl tetrahydrofurfurane carboxylic acid*, $HOCH_2.CH(O)CH(OH)CH(OH)CHCO_2H$, since acetic anhydride converts it into the *acetyl* derivative of *hydroxymethyl pyromucic acid*, $CH_3CO.O.CH_2.C(O):CH.CH:C\text{-}CO_2H$ (Vol. II.), B. **36**, 2587). Oxidation with H_2O_2 and ferrous sulphate degrades chitonic acid into d-arabinose or d-ribose (p. 619) (B. **35**, 4016).

Glucosaminic Acid, *α-Amino-βγδε-tetrahydroxycaproic Acid,* $HOCH_2[CHOH]_3CH(NH_2)CO_2H$, is known in d-, l-, [d+l]-forms. d- and l-glucosaminic acid are prepared from d- and l-arabinosimine (p. 636), hydrocyanic and hydrochloric acids, and unite to form the less soluble [d+l] acid. d-Glucosaminic acid is also prepared from d-glucosamine and bromine water. Alcohol and hydrochloric acid convert it into a lactone-like syrup, which, on reduction with sodium amalgam, regenerates d-glucosamine. Reduction with hydriodic acid produces α-amino-caproic acid; with nitrous acid it forms chitaric acid (see above). It yields isomeric ***β-aminoglucoheptonic acids,*** $CH_2OH[CHOH]_3CH(NH_2)CHOHCO_2H$, with hydrocyanic and hydrochloric acids (B. **36**, 27, 618).

Galaheptosaminic Acid, $CH_2OH[CHOH]_4CH(NH)_2CO_2H$, m.p. 240° with decomposition, is prepared from galactosimine (p. 636) and hydrocyanic and hydrochloric acids (B. **35**, 3801).

B. HEXOSE CARBOXYLIC ACIDS, HEXAHYDROXYMONOCARBOXYLIC ACIDS

Acids of this kind have been obtained from d-dextrose, d-mannose, d-galactose, and d-fructose by the addition of hydrocyanic acid, and the subsequent saponification of the nitrile with hydrochloric acid.

(1) **Mannoheptonic Acid,** is known in three modifications:

d-**Mannose Carboxylic Acid,** d-*Mannoheptonic Acid,* $CH_2OH.[CHOH]_5.CO_2H$, is obtained from d-mannose (A. **272,** 197); *phenylhydrazide,* m.p. about 220° with decomposition; *lactone,* m.p. 149°. Sodium amalgam reduces the lactone to d-mannoheptose, $C_7H_{14}O_7$, and then to the heptahydric alcohol perseïtol, $C_7H_{16}O_7$ (B. **23**, 936, 2226). Hydriodic acid reduces the acid to heptolactone and heptylic acid (see above and B. **22,** 370). When oxidized it yields l-pentahydroxypimelic acid (A. **272,** 194). l-*Mannose Carboxylic Acid* is obtained from l-mannose; *phenylhydrazide,* m.p. about 220°; *lactone,* m.p. 154°. [d+l]-Mannose carboxylic acid is formed from d- and l-mannose carboxylic acid, as well as from [d+]-mannose (A. **272,** 184).

(2) α,d-**Dextrose Carboxylic Acid,** α,d-*Glucoheptonic Acid,* $CH_2OH[CHOH]_5CO_2H$, is formed (1) together with the β-acid from d-dextrose; (2) on heating the β-acid to 140° with pyridine; (3) by the hydrolysis of lactose- and maltose carboxylic acids (p. 661) (A. **272,** 200); *lactone,* m.p. 140–145°. Hydriodic acid reduces it to heptolactone and normal heptylic acid. Sodium amalgam reduces the lactone to *dextroheptose* (d-glucoheptose). *Dimethylene α-Glucoheptonic Lactone,* $C_7H_8(CH_2)_2O_7$, m.p. 280°. The acid, when oxidized, is converted into inactive pentahydroxypimelic acid (p. 655); *phenylhydrazide,* m.p. 171° (B. **19,** 1916; **23,** 936; space-formula, A. **270,** 65).

*β,*d-*Dextrose Carboxylic Acid* is formed together with the α-acid from dextrose; *phenylhydrazide,* m.p. 151°; *lactone,* m.p. 151°, and yields β, d-glucophetose on reduction (p. 637). *Dimethylene β-Glucoheptonic Lactone,* m.p. 230° (A. **299,** 328; **310,** 181).

α,d-**Galactose Carboxylic Acid,** *α-Galaheptonic Acid,* $CH_2OH[CHOH]_5CO_2H$, m.p. 145°, is produced together with *β-galaheptonic acid* from galactose; *lactone,* m.p. 150°. Sodium amalgam changes it into α-galaheptose (p. 637). When oxidized it yields carboxy-d-galactonic acid (p. 655) (A. **288,** 39).

d-**Fructose Carboxylic Acid,** $CH_2OH.[CHOH]_3C(OH)(CO_2H)CH_2OH$, is obtained from fructose or lævulose by the action of hydrocyanic acid. It yields tetrahydroxybutane tricarboxylic acid when it is oxidized. Its *lactone,* m.p. 130°, when reduced with sodium amalgam two aldoheptoses with branched C-chains result (B. **23,** 937). Reduction with hydriodic acid forms heptolactone and heptylic acid, $C_7H_{14}O_2$. The latter is identical with methyl n.-butyl acetic acid (p. 261). Hence it is evident that *lævulose* is a *ketone-alcohol* (*Kiliani,* B. **19,** 1914; **23,** 451; **24,** 348).

C. ALDOHEPTOSE CARBOXYLIC ACIDS, HEPTAHYDROXYCARBOXYLIC ACIDS

d-**Manno-octonic Acid,** $CH_2OH.[CHOH]_6CO_2H$, has been obtained from d-mannoheptose (p. 637); ***hydrazide,*** m.p. 243°; *lactone,* m.p. about 168°, has a neutral reaction, and a sweet taste. By reduction it forms d-manno-octose (p. 637). α- and *β-Gluco-octonolactone*, m.p. 145° and 186° (A. **270**, 93). *α-Gala-octonolactone*, from a α-galaheptose (A. **288**, 149).

D. ALDO-OCTOSE CARBOXYLIC ACIDS, OCTOHYDROXYCARBOXYLIC ACIDS

d-Mannononoic Acid, $CH_2OH[CHOH]_7CO_2H$, has been obtained from d-manno-octose; *hydrazide*, m.p. 254°; *lactone*, m.p. 176°. When reduced it forms d-**mannononose** (p. 637).

6. TETRAHYDROXY- AND PENTAHYDROXY-ALDEHYDE ACIDS

d-Glucuronic Acid, $CHO(CHOH)_4CO_2H$, is obtained by decomposing euxanthic acid (Vol. II.) on boiling with dilute sulphuric acid. Various glucoside-like compounds of glucuronic acid with camphor, borneol, chloral, phenol, and different other bodies (B. **19**, 2919, R. 762) occur in urine after the introduction of these compounds into the animal organism. In this change the substances mentioned combine with the aldehyde group of dextrose, the primary alcohol group of which is then oxidized. Boiling acids decompose them into their components. Synthetically, such conjugated glucuronic acid can also be obtained, *e.g. Diacetyl Bromoglucurolactone*, $OCHBrCH(O_2C_2H_3)CH.CHCH(O_2C_2H_3)COO$, m.p. 90°, the product of reaction between glucuronic lactone and acetyl bromide reacting with euxanthone (Vol. II.) or phenol (Vol. II.) and sodium alcoholate, gives rise to euxanthic or phenol glucuronic acid (C. 1905, I. 1086). Glycuronic acid can be identified in animal secretions by the blue coloured substance, soluble in ether, which is formed with β-naphthoresorcinol and hydrochloric acid (B. **41**, 1788).

Glucuronic acid forms a syrup, which rapidly passes into the sweet-tasting *lactone*, $C_6H_8O_6$, m.p. 175°. (For derivatives of the same see B. **33**, 3315). Bromine water oxidizes it to saccharic acid. It also appears that when saccharic acid is reduced glucuronic acid results (B. **23**, 937), and by further reduction d-gluconic acid (p. 649) is formed (B. **24**, 525). The acid unites with potassium cyanide to form the half nitrile of *α-glucopentahydroxypimelic acid* (p. 655); with three molecules of phenylhydrazine to form an *osazone*, m.p. 200–205°; with urea, accompanied by loss of water (C. 1905, I. 1084). *Urochloralic Acid*, $C_7H_{11}Cl_3O_7$, m.p. 142°, decomposes with water absorption on boiling with dilute hydrochloric or sulphuric acid into glucuronic acid and trichlorethyl alcohol (p. 117). *Urobutyl Chloralic Acid*, $C_{10}H_{15}Cl_3O_7$, decomposes, like the preceding body, into glucuronic acid and ααβ-trichlorobutyl alcohol (p. 118).

Aldehydogalactonic Acid, $COH[CHOH]_5CO_2H$, is obtained from d-galactose carboxylic acid, and may be converted into carboxygalactonic acid (p. 655).

7. **Monoketotetrahydroxy Carboxylic Acids.** *Hydroxyglucuronic Acid*, $HOCH_2.CO[CHOH]_3CO_2H$, is formed, together with d-arabinose, when calcium gluconate is oxidized; also by bacterial action (B. **32**, 2269), as in the case of the n.-hexitols (p. 641).

8. POLYHYDROXYDICARBOXYLIC ACIDS

A. TETRAHYDROXYDICARBOXYLIC ACIDS

These are obtained by the oxidation of various carbohydrates with nitric acid, and are readily prepared from the corresponding mono-carboxylic acids upon oxidation with nitric acid. Mannosaccharic acid, the saccharic acids, and the mucic acids are the most important representatives of the series. Gluconic acid (p. 649) yields saccharic acid, galactonic acid (p. 650), mucic acid, and mannonic acid (p. 648) mannosaccharic acid. Their lactones, by very careful reduction, can be converted into aldehydehydroxycarboxylic acids and hydroxymonocarboxylic acids. When reduced by HI and phosphorus the preceding acids are converted into normal adipic acid (p. 505), hence all of them must be considered as normal space-isomeric tetrahydroxyadipic acids. Theoretically, ten simple and four double modifications are possible, as in the case of the n.-hexitols (p. 641). All the tetrahydroxyadipic acids, when heated with hydrochloric or hydrobromic acid, change more or less readily to dehydromucic acid (B. **24**, 2140).

(1) **Mannosaccharic Acid,** $CO_2H[CHOH]_4CO_2H$, is known in three modifications (space-formula, p. 641), which pass into double lactones when they are liberated from their salts. They also result upon oxidizing the three mannonic acids with nitric acid (p. 648).

[d+l]-*Mannosaccharolactone*, $C_6H_6O_6$, m.p. 190° with decomposition, is formed by the union of d- and l-mannosaccharolactone; and also from [d+l]-mannolactone; *diamide*, m.p. 184°; *dihydrazide*, m.p. 220–225° (B. **24**, 545).

d-*Mannosaccharolactone*, $C_6H_6O_6+2H_2O$, m.p. 181° anhydrous, is produced when d-mannitol, d-mannose, and d-mannonic acid are oxidized with nitric acid; *diamide*, m.p. 189°; *dihydrazide*, m.p. 212° (B. **24**, 544). l-*Mannosaccharolactone, Metasaccharic Acid*, $C_6H_6O_6+2H_2O$, m.p. 68°, anhydrous, 180°, is produced when l-mannonic acid and the lactone of l-arabinose carboxylic acid are oxidized (B. **20**, 341, 2713); *diamide*, m.p. 190°; *dihydrazide*, m.p. 213°. *Diactyl l-Mannosaccharolactone*, m.p. 155° (B. **21**, 1422; **22**, 525; **24**, 541).

(2) d- and **l-Idosaccharic Acids** are syrups. They are obtained by oxidizing the corresponding idonic acid (p. 650) (space-formula, p. 642).

(3) **Saccharic Acid,** $CO_2H[CHOH]_4CO_2H$, exists in three modifications (space-formulæ, p. 642); of these the d-saccharic acid is ordinary saccharic acid.

[d+l]-*Saccharic Acid* is formed by the oxidation of [d+l]-gluconic acid. Its monopotassium salt is formed on mixing solutions of equal quantities of the d- and l-salt; *dihydrazide*, m.p. 210° (B. **23**, 2622).

Ordinary, or d-saccharic acid, results in the oxidation of sucrose (B. **21**, R. 472), d-dextrose (grape sugar), d-gluconic acid and d-gluconic lactone (B. **24**, 521), and many carbohydrates with nitric acid; also from the action of bromine water on glucuronic acid (p. 652).

If forms a deliquescent mass, readily soluble in alcohol. If the pure syrupy acid be allowed to stand for some time, it changes to a crystalline *lactonic acid*, $C_6H_8O_7$, m.p. 131°. It is converted into glucuronic acid when reduced with sodium amalgam. Hydriodic acid reduces it to adipic acid. When oxidized with nitric acid, d-*tartaric acid* (B. **27**, 396) and oxalic acid are formed

Salts.—The *hydrogen potassium salt*, $C_6H_9O_8K$, and the *ammonium salt*, $C_6H_9O_8(NH_4)$, dissolve with difficulty in cold water; *diethyl ester* is crystalline; *amide* is a white powder; *tetra-acetate*, m.p. 61°. Acetyl chloride, acting on free saccharic acid, converts it into the *lactone of diacetyl saccharic acid*, $C_6H_4(O.C_2H_3O)_2O_4$, m.p. 188°. *Monomethylene Saccharic Acid* (A. **292**, 40). The *diamide* is a white powder; *dihydrazide*, m.p. 210° with decomposition (B. **21**, R. 186).

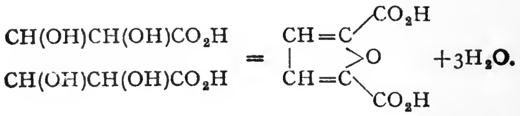
l-*Saccharic Acid* is obtained upon oxidizing l-gluconic acid with nitric acid. It s quite similar to d-saccharic acid, but is lævo-rotatory. It also forms a *dihydrazide*. m.p. 214°.

(4) **Mucic Acid**, *Acidum mucicum*, $CO_2H[CHOH]_4CO_2H$, m.p. 210° with decomposition, corresponds in constitution with dulcitol, and possesses the space-formula No. 7 (p. 642), one of the two theoretically possible forms of tetrahydroxyadipic acid, optically inactive through internal compensation. This is supported by its oxidation to racemic acid, and its formation by oxidation from α-rhamnose carboxylic acid (p. 650) (B. **27**, 396).

It is also obtained in the oxidation of dulcitol, lactose (Preparation, A. **227**, 224), d- and l-galactose, d- and l-galactonic acid, and nearly all the gum varieties.

It is a white crystalline powder, almost insoluble in cold water and alcohol. When boiled for some time with water it passes into a readily soluble lactonic acid, $C_6H_8O_7$, formerly designated *paramucic acid*, d-saccharolactonic acid (p. 653; B. **24**, 2141). Reduction changes this mucic lactonic acid into [d+l]-galactonic acid (p. 650 : B. **25**, 1247). Mucic acid heated to 140° with pyridine becomes *allomucic acid*, from which it can be reformed under similar conditions.

The ready conversion of mucic acid into furfurane derivatives is rather remarkable. Digestion with fuming hydrochloric or hydrobromic acid changes it to furfurane dicarboxylic acid (*dehydromucic acid*):



When mucic acid is heated alone it loses carbon dioxide and becomes converted into furfurane monocarboxylic acid (*pyromucic acid*):

$$C_4H_4(OH)_4(CO_2H)_2 = C_4H_3O.CO_2H + 3H_2O + CO_2.$$

Heated with barium sulphide it passes in like manner into α-thiophene carboxylic acid (B. **18**, 457).

Pyrrole is produced when the diammonium salt is heated:

$$C_6H_8(NH_4)_2O_8 = C_4H_4NH + NH_3 + 2CO_2 + 4H_2O.$$

Salts and Esters.—The *di-potassium salt* and *di-ammonium salt*, crystallize well and dissolve with difficulty in cold water; the *hydrogen salts* dissolve readily. The *silver salt*, $C_6H_8Ag_2O_8$, is an insoluble precipitate; *diethyl ester*, m.p. 158°; *tetra-acetate*, m.p. 177° (B. **21**, R. 186; C. 1898, II. 963).

See p. 522 for the action of PCl_5 on mucic acid.

(5) **Allomucic Acid**, $C_6H_{10}O_8$, m.p. 166–171°, is optically inactive, and more soluble than mucic acid, from which it is obtained on heating with pyridine, and into which it also passes (see mucic acid (B. **24**, 2136).

(6) **Talomucic Acid**, $CO_2H[CHOH]_4CO_2H$, is known in two space-isomeric modifications:

d-*Talomucic Acid*, m.p. about 158° with decomposition, and resulting from the oxidation of d-talonic acid (B. **24**, 3625).

l-*Talomucic Acid*, prepared by oxidizing β-rhamnose carboxylic acid (p. 650) (B. **27**, 384).

(7) **Isosaccharic Acid**, $CO_2H.\overbrace{CH.CHOH.CHOH.CH}^{O}CO_2H$, m.p. 185°. $[\alpha]_D = +46{\cdot}1°$ results from glucosamine (p. 636) upon oxidizing it with nitric acid (B. **19**, 1258; see also Chitonic and Chitaric Acids, p. 650). The acid itself

and some of its derivatives must be regarded as compounds of tetrahydrofurfurane, as is evident from the constitution formula of the acid. Other derivatives should be referred to isosaccharic acid $+H_2O$—that is, to tetrahydroxyadipic acid, and they are described as derivatives of *norisosaccharic acid;* for example, the *diethyl ester,* $C_6H_8O_8(C_2H_5)_2$, m.p. 73°, which changes in the desiccator to the *Diethyl Ester* of *Isosaccharic Acid,* $C_6H_8O_7(C_2H_5)_2$, m.p. 101°. *Diacetyl Isosaccharic Ester,* m.p. 49° (B. **27,** 118).

B. PENTAHYDROXYDICARBOXYLIC ACIDS

Pentahydroxypimelic Acid, [Glucoheptanepentol Diacid], $CO_2H[CHOH]_5CO_2H$, is produced in the oxidation of dextrose carboxylic acid with nitric acid; *lactone* is crystalline, m.p. 143° (B. **19,** 1917).

α-Carboxygalactonic Acid, [α-Galaheptanepentol Diacid], $CO_2H[CHOH]_5CO_2H$, m.p. 171° with decomposition, is formed in the oxidation of α-d-galactose carboxylic acid with nitric acid. It dissolves with difficulty in water, and crystallizes in plates.

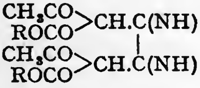
β-Galaheptanepentol Diacid, is formed from β-galaheptonic acid and nitric acid (A. **288,** 155).

9. Tetraketodicarboxylic Acids.

Acetonyl Acetone Dioxalic Ester, $C_2H_5O_2C.CO.CH_2COCH_2.CH_2COCH_2.CO.CO_2C_2H_5$, m.p. 101°, is prepared from acetonyl acetone (p. 350), oxalic ester, and sodium in ethereal solution. Hydrazine produces a dilactazam, ethane dipyrazyl carboxylic ester (B. **33,** 1220).

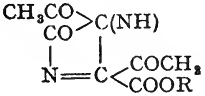
αα₁-Diacetyl ββ-Diketoadipic Acid, $CH_3CO.CH(CO_2H)COCOCH(COCH_3)CO_2H$, is the hypothetical parent substance from which is derived *Dicyano-bis-acetoacetic Ester, αα₁-Diacetyl ββ₁-Diiminoadipic Ester* (1), m.p. 132°. This is prepared from dicyanomonoacetoacetic ester (p. 608), acetoacetic ester, and a little sodium alcoholate. Alkalis convert it first into a yellow *lactam* (2), m.p. 136°, and later into the free *acid,* m.p. 230° with decomposition. Reduction with sodium amalgam, accompanied by simultaneous *ketone decomposition,* forms *αδ-Diacetyl βγ-Diaminovaleric Ester* (3), m.p. 35° (A. **332,** 138):

(1)



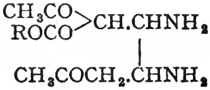
$$\begin{array}{l} {CH_3CO \atop ROCO}\!>\!CH.C(NH) \\ \qquad\qquad\quad | \\ {CH_3CO \atop ROCO}\!>\!CH.C(NH) \end{array}$$

(2)



$$\begin{array}{l} {CH_3CO \atop CO}\!>\!C(NH) \\ \quad |\qquad\quad | \\ \;N{=\!=}C\!<\!{COCH_3 \atop COOR} \end{array}$$

(3)



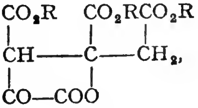
$$\begin{array}{r} {CH_3CO \atop ROCO}\!>\!CH.CHNH_2 \\ | \qquad\quad \\ CH_3COCH_2.CHNH_2 \end{array}$$

10. Triketotricarboxylic Acids.

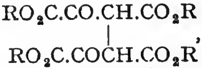
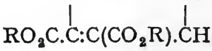
α-Acetyl ββ₁-Diketoadipic α₁-Carboxylic Acid, $CH_3COCH(CO_2H)COCOCH(CO_2H)_2$, has, as a derivative, *Dicyanacetoacetic Malonic Ester,* $CH_3COCH(CO_2C_2H_5)-C(NH)C(NH)CH(.CO_2C_2H_5)_2$, m.p. 93°, the reaction product of dicyanacetoacetic ester (p. 608) and malonic ester (A. **332,** 144). But dicyanomalonic ester and sodium acetoacetic ester yield *Dicyanomalonic Acetoacetic Ester Lactam,* m.p. 137° (indefinite). Similarly, dicyanocyanacetic ester and sodium acetoacetic ester give rise to *Dicyanocyanacetic Acetoacetic Ester Lactam,* m.p. 168° (indefinite) (A. **332,** 129).

Oxalyl Dimalonic Acid, ββ-Diketoadipic αα₁-Dicarboxylic Acid, $(HO_2C)_2CH.CO.-COCH(CO_2H)_2$, is the hypothetical parent substance of *dicyano-bis-malonic acid,* $(HO_2C)_2CHC(NH).C(NH).CH(CO_2H)_2$, of which the *dilactam* is formed from dicyanogen and sodium malonic ester. Sodium amalgam reduces it to diaminadipic dicarboxylic acid, which loses CO_2 and becomes changed into ββ₁-diaminoadipic acid (p. 606) (A. **332,** 122).

11. Hydroxyketotetracarboxylic Acids.

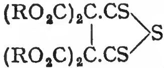
Oxalocitric Lactone Ethyl Ester,  $\begin{array}{lll} CO_2R & CO_2R & CO_2R \\ | & | & | \\ CH{-\!-\!-} & C{-\!-\!-} & CH_2 \\ | & | & \\ CO{-\!-} & COO & \end{array}$, b.p.$_{30}$ 210°, is prepared from two molecules of oxalacetic ester by aldol condensation and lactone formation (A. **295,** 347).

12. **Diketotetracarboxylic Acids.**

Dioxalosuccinic Ethyl Ester,  $\begin{array}{c}RO_2C.CO.CH.CO_2R\\ |\\ RO_2C.COCH.CO_2R\end{array}$, is formed by the condensation, of succinic and oxalic esters by sodium ethoxide. When distilled under greatly reduced pressure it loses CO and is converted into ethane tetracarboxylic ester. When liberated from its disodium compound by sulphuric acid it gives *Dioxalosuccinic Lactone Ethyl Ester,*  $\begin{array}{l}\qquad\quad O\text{———}CO\\ \qquad\quad |\qquad\quad |\\ RO_2C.C{:}C(CO_2R).CH.CO.CO_2R\end{array}$, m.p. 89° (A. 285, 11).

13. **Hexacarboxylic Acids.**

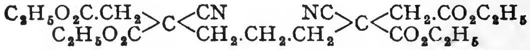
Ethane Hexacarboxylic Acid, $(CO_2H)_3C.C(CO_2H)_3$, is not known, though derivatives exist, of which two may be mentioned.

Bis-cyanomalonic Ester, $NC.C(CO_2C_2H_5)_2.C(CO_2C_2H_5)CN+1\frac{1}{2}H_2O$, m.p. 57°, is obtained by electrolysis of sodium cyanomalonic ester (C. 1905, I. 1141). Also, by the action of carbon disulphide and bromine on sodium malonic ester and sodium cyanacetic ester there is formed *Dithiotetrahydrothiophene Tetracarboxylic Ester,*  $\left.\begin{array}{l}(RO_2C)_2C.CS\\ \qquad\ \ |\\ (RO_2C)_2C.CS\end{array}\right>S$, (B. 34, 1043).

Pentane ααγγεε-Hexacarboxylic Ester, $(RO_2C)_2CH.CH_2.C(CO_2R)_2CH_2CH(CO_2R)_2$, m.p. 54°, b.p.$_{15}$ 155°, is prepared by condensation of two molecules of formaldehyde and three of malonic ester brought about by diethylamine. Its disodium salt and bromine produce a pentamethylene derivative (C. 1900, I. 802). On an isomeric pentane hexacarboxylic ester, $CH_2[C(CO_2R)_2.CH_2CO_2R]_2$, see C. 1902, II. 733.

Hexane 1,3,3,4,4,6,-*Hexacarboxylic Ester,* $C_2H_5O_2CCH_2CH_2C(CO_2C_2H_5)_2C(CO_2C_2H_5)_2CH_2CH_2.CO_2C_2H_5$, is formed from disodium ethane tetracarboxylic ester and two molecules of β-iodopropionic ester. Hydrolysis and decomposition produces *diglutaric acid* (C. 1903, I. 628).

Heptane Hexacarboxylic Acid. A derivative of this acid is ***Trimethylene Dicyanosuccinic Ester:***



$$\begin{array}{r}C_2H_5O_2C.CH_2\\ C_2H_5O_2C\end{array}\!>C<\!\begin{array}{l}CN\\ CH_2.CH_2.CH_2\end{array}\!\!\!\begin{array}{r}NC\\ \ \end{array}\!>C<\!\begin{array}{l}CH_2.CO_2C_2H_5\\ CO_2C_2H_5\end{array}$$

m.p. 69°, b.p.$_7$ 215°, produced by the interaction of trimethylene bromide on sodium cyanosuccinic ester (C. 1897, II. 520; 1899, I. 826).

Appendix. **Higher polycarboxylic ethyl esters** may be obtained from sodium propane pentacarboxylic ester, chloromalonic ester, and chloropropane pentacarboxylic ester, giving rise to *Butane Heptacarboxylic Ester,* $C_4H_3(CO_2C_2H_5)_7$, b.p.$_{130}$ 280–285°, and *Hexane Dekacarboxylic Ester,* $C_6H_4(CO_2C_2H_5)_{10}$, a yellow oil. *Octane Tesserakaideka-carboxylic Ester,* $C_8H_4(CO_2C_2H_5)_{14}$, is prepared from sodium butane heptacarboxylic ester and chlorobutane heptacarboxylic ester. It is the highest known carboxylic ester, and consists of a thick oil (B. 21, 2111).

CARBOHYDRATES *

This term is applied to a large class of compounds, widely distributed in nature, comprising natural sugars, and substances related to them. They contain six, or a multiple of six carbon atoms. The ratio of their hydrogen and oxygen atoms is the same as that of these elements in water, hence their name.

Most of the carbohydrates have their origin in plants, although some are probably also produced in the animal organism. Those

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* "Kohlenhydrate," von B. Tollens. "Die Chemie der Zuckerarten," von E. O. von Lippmann, II. Auflage, 1895. "Die Chemie der Kohlenhydrate und ihre Bedeutung für die Physiologie," von E. Fischer, 1894.

which occur in the vegetable kingdom meet with the most extensive employment.

Carbohydrates serve for the preparation of alcoholic drinks (p. 114). Sugars, particularly cane sugar, form the basis of many foodstuffs. Starch is the chief ingredient of flour from which bread, the most important food, is made. It is found stored up in potatoes and grain fruits. Cellulose, related to it, is the principal constituent of wood, cotton, etc., and is applied in paper-making and for the production of explosives. The carbohydrates in conjunction with the proteins constitute the most important food-materials for man.

Their molecular magnitude is the basis of their arrangement into these classes:

Monoses, or *Monosaccharides*,
Saccharobioses, or *Disaccharides*,
Saccharotrioses, or *Trisaccharides*,
Polysaccharides.

The monosaccharides, including dextrose and lævulose, have already been discussed in connection with the hexahydric alcohols, of which they are the first oxidation products (p. 626).

Nearly all of the naturally occurring carbohydrates are *optically active*, i.e., their solutions rotate the plane of polarization of light (p. 54). The specific rotatory power is not only influenced by the temperature and concentration of their solutions, but very frequently also by the presence of inactive substances (B. **21,** 2588, 2599). Some representatives also exhibit the phenomena of birotation and semirotation (p. 632). Constant rotation is generally attained by heating the solutions for a brief period. The determination of this rotatory power of the carbohydrates by means of the saccharimeter serves to ascertain their purity, or for the determination of their amount when dissolved: *optical sugar test, saccharimetry* (p. 659).

A. DISACCHARIDES, SACCHAROBIOSES

Disaccharides, consisting of two molecules of dextroses or monoses (p. 625), hence termed *bioses*, have up to the present only been known among the hexoses, $C_6H_{12}O_6$ (see Galacto-arabinose (p. 660), their formula being $C_{12}H_{22}O_{11}$. By the absorption of water they are resolved into two molecules of the hexoses:

$$C_{12}H_{22}O_{11}+H_2O = 2C_6H_{12}O_6.$$

This reaction is known as hydrolytic decomposition or *hydrolysis*. The higher carbohydrates are also capable of undergoing this change.

The constitution of the disaccharides indicates that they are ether-like anhydrides of the hexoses, in which the union occurs either through the alcohol and the aldehydo- or keto-group. Lactose and maltose also contain the aldose group, CH(OH).CHO, as is shown by their reducing *Fehling's* solution upon boiling, forming osazones with phenylhydrazine, and when oxidized with bromine water, yielding monobasic acids, $C_{12}H_{22}O_{12}$, lacto- and maltobionic acids (p. 660) (B. **21,** 2633; **22,** 361). Sucrose does not show reducing power and does not yield an osazone; the reducing groups of dextrose and lævulose appear to be combined together in this compound. The osazones of some of these sugars split off glyoxal osazone when treated with alkalis (B. **29**, R. 991) (comp. also the formation of glyoxalin from the hexoses and ammonia, p. 630).

The hydrolysis of the saccharobioses has already been described in detail under alcoholic *fermentation* (p. 112); it is brought about by unorganized *ferments*, such as *diastase* and *synaptase* or *emulsin* (contained in sweet and bitter almonds). *Invertin* (changing a dextro-rotatory sugar solution into lævo-rotatory *invert sugar*), *ptyalin* (the ferment of saliva), *pancreas diastase*, and other animal secretions exert a like action (p. 677).

When the di- and poly-saccharides are heated with water and a little acid they undergo hydrolysis, with a rapidity which, according to *Ostwald*, bears a close relation to the affinity of the acids (J. pr. Chem. [2] **31**, 307). Certain inorganic salts, and also glycerol, are capable of inverting sucrose (B. **29**, R. 950; **27**, R. 574).

Prolonged or strong heating with acid brings about a *reversion*, in which the dextroses, and particularly lævulose, undergo a backward condensation to dextrin-like substances (B. **23**, 2094). Also ferments such as *maltase*, *kefir-lactase*, etc., can cause reversion of the hexoses into disaccharides. It is also possible to build up some of the disaccharides from acetochlorodextrose (p. 634) or acetochlorogalactose (p. 635) with sodium dextrose or sodium galactose in alcohol solution. From this the galactosidodextrose appears to be identical with melibiose (B. **35**, 3144).

Sucrose, *Saccharose*, *Saccharobiose*, $C_{12}H_{22}O_{11}$, m.p. 160°, D=1·606, $[\alpha]_D^{20}=+66{\cdot}5°$ (B. **17**, 1757), the most important of the sugars, occurs in the juice of many plants, chiefly in sugar cane (*Saccharum officinarum*) (20 per cent. of the juice), in some varieties of maple, in the sorghum (*Sorghum saccharatum*), and in beet-roots (*Beta maritima*) (10–20 per cent.), from which it is prepared on a commercial scale; and also in the seeds of some plants (B. **27**, 62).

Whilst the hexoses occur mainly in fruits, sucrose is usually contained in the stalks of plants. The sugar cane contains, together with the sucrose, lævulose and dextrose, of which the quantity diminishes with the growth of the plant.

Historical.—Sugar has been obtained from sugar cane from the earliest times. In the middle ages sugar cane was a rarity in Germany; it was only after the discovery of America that it was gradually introduced as a sweetening agent. In 1747 *Marggraf*,* in Berlin, discovered sucrose in beet-roots, an observation which became the basis of the beet-sugar industry. In 1801 *Achard*, in Silesia, erected the first beet-sugar factory. The continental blockade forced by Napoleon I. hastened the development of the new industry, which during the last fifty years has attained a constantly increasing importance in Germany, where about one-fifth of the total sugar yield of the world is produced. In the year 1906–7, 369 factories consumed 14,186,536 tons (1 ton = 1000 kilos) of beets, which produced 2,242,000 tons of beet-sugar. The total production of sugar in the world was, in 1906–7, about 7,120,000 tons of beet-sugar and 5,140,000 tons of cane sugar.

Technical Preparation.†—The sugar is best removed from the cane and from

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* Ein Jahrhundert chemischer Forschung unter dem Schirme der Hohenzollern, von A. W. Hofmann, 1881.

† Hdb. d. chem. Technologie, Ferd. Fischer, 1893. S. 851–888.

the finely divided beets by the diffusion process. The saccharine juice diffuses through the cell walls, whereas the colloids in the latter remain behind. The filtered sap is heated to 80–90° with milk of lime, to saturate the acids, and precipitate the proteins. The juice is next treated with carbon dioxide, phosphoric acid, or SO_2 (to arrest fermentation), filtered through animal charcoal, and is concentrated in vacuum pans till it crystallises. The mother-liquor, *melasse*, is separated by centrifugation, and the solid is washed with a pure sugar solution ("*Klärsel*") or purified by recrystallisation, and thus forms *refined sugar*.

Sugar may be obtained from the syrupy mother liquor—the molasses, which cannot be brought to crystallization:

(1) By *osmosis*, depending upon diffusion through parchment paper, in apparatus similar to filter presses.

(2) By *washing* (*Scheibler*, 1865). The sparingly soluble saccharates of lime and strontium are obtained from the molasses (see below) and these are freed from impurities by washing with water or dilute alcohol. The purified saccharates are afterwards decomposed by carbon dioxide, and the juice which is then obtained, after the above plan, is further worked up.

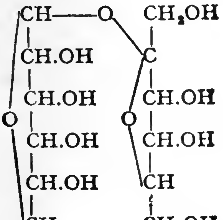
The molasses is also converted into *rum* (p. 114).

Properties.—When its solutions are evaporated slowly, sucrose separates in large monoclinic prisms, and dissolves in one-third part water of medium temperature; it dissolves with difficulty in alcohol. After being melted it solidifies to an amorphous glassy mass (sugar candy), which in time again becomes crystalline and non-transparent. At 190–200° it changes to a brown non-crystallizable mass, called *caramel*, which finds application in colouring food stuffs.

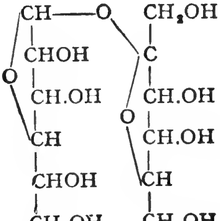
The quantity of sugar in solution may be determined by polarization, using the apparatus of *Soleil-Ventzke-Scheibler*, or the half-shadow instrument devised by *Schmidt* and *Hänsch* (B. **27**, 2282), as well as from the specific gravity by means of the *saccharimeter* of *Brix*.

Reactions and Constitution.—Sucrose is hydrolyzed into d-dextrose and d-lævulose (invert sugar) when boiled with dilute acids; and also by the action of ferments. It is only after this occurs that it is capable of reducing *Fehling's* solution. Mixed with concentrated sulphuric acid it is converted into a black, humus-like body. d-Saccharic acid, tartaric acid and oxalic acid are formed when it is boiled with nitric acid. Sucrose heated to 160° with an excess of acetic anhydride gives *octacetyl ester*, $C_{12}H_{14}O_3(O.COCH_3)_8$, m.p. 67° (B. **34**, 4347). This latter fact and the failure of sucrose to reduce *Fehling's* solution under ordinary conditions are made to appear in the following formulæ:

I. (*Tollens*) (B. **16**, 923)



II. (*E. Fischer*) (B. **26**, 2405)



Saccharates.—Sucrose unites with bases to form *saccharates*, $C_{12}H_{22}O_{11}.CaO + 2H_2O$, is precipitated by alcohol, whilst $C_{12}H_{22}O_{11}.2CaO$ crystallizes on cooling. $C_{12}H_{22}O_{11}.3CaO$ dissolves with great difficulty (B. **16**, 2764). Similar compounds are formed with the oxides of strontium and barium (see above) (B. **16**, 984).

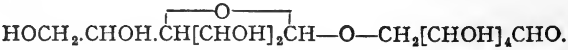
Tetranitrosaccharose, $C_{12}H_{18}(NO_2)_4O_{11}$, explodes violently.

Lactose, *Milk Sugar, Lactobiose,* $C_{12}H_{22}O_{11}+H_2O$, m.p. anhydrous 205° with decomposition, occurs in the milk of mammals, in the amniotic liquor of cows, and in certain pathological secretions. *Fabriccio Bartoletti,* of Bologna, discovered it in 1615.

Lactose is prepared from whey, which is evaporated to the point of crystallization, and the sugar which separates is purified by repeated crystallization.

Lactose crystallizes in white, hard, rhombic prisms, which become anhydrous at 140°. It is soluble in 6 parts cold or $2\frac{1}{2}$ parts hot water, has a faint sweet taste, and is insoluble in alcohol. Its aqueous solution is dextro-rotatory and exhibits *birotation* (p. 632). It resembles the hexoses in reducing ammoniacal silver solutions in the cold, but in case of alkaline copper solutions boiling is necessary.

Reactions and Constitution.—Lactose is decomposed into galactose and d-dextrose by being heated with dilute acids. It is only slowly attacked by yeast, but it readily undergoes lactic acid fermentation (pp. 363, 631). Nitric acid converts it into d-saccharic and mucic acids. Bromine produces *lactobionic acid,* $C_{12}H_{22}O_{12}$, which splits up into d-gluconic acid and d-galactose; whilst oxidation with H_2O_2 breaks it down, as it does the aldoses (p. 617) into *galacto-arabinose,* $C_{11}H_{20}O_{10}$. The latter forms an *osazone,* m.p. 237°, and is hydrolyzed into d-galactose and d-arabinose (B. **33**, 1802). Lactose takes up hydrocyanic acid and forms ultimately *lactose carboxylic acid,* $C_{12}H_{23}O_{11}.CO_2H$, which decomposes into d-glucoheptonic acid (p. 651) and d-galactose (A. **272**, 198). See also Isosaccharine (p. 620). *Lactosazone,* $C_{12}H_{20}O_9(N_2HC_6H_5)_2$, m.p. 200° (B. **20**, 829). *Octo-acetyl Lactose,* $C_{12}H_{14}O_3[OCOCH_3]_8$, m.p. 106°, yields, with fluid HCl *hepta-acetyl chlorolactose,* $C_{12}H_{14}O_3OCOCH_3)_7Cl$. *Hepta-acetyl Bromolactose* is formed from lactose and acetyl bromide. The two last-named lactose compounds exhibit polymorphism. When treated with methyl alcohol and silver carbonate, they yield *hepta-acetyl methyl lactose,* $C_{12}H_{14}O_3(OCOCH_3)_7CH_3$ (B. **35**, 841; C. 1902, II. 1416). These changes demonstrate the formula of lactose to be that of *galactodextrose:*



$$\mathrm{HOCH_2.CHOH.}\overbrace{\mathrm{CH[CHOH]_2CH}}^{\mathrm{O}}\mathrm{—O—CH_2[CHOH]_4CHO.}$$

Lactic acid forms a crystalline compound with aminoguanidine nitrate and sulphate (B. **28**, 2614).

Maltose, *Malt Sugar, Maltobiose,* $C_{12}H_{22}O_{11}+H_2O$, $[a]_D^{20}=137°$ (B. **28**, R. 990; C. 1897, II. 695), is a variety of sugar formed, together with dextrin, by the action of malt diastase (p. 115) on starch as in the mash of whiskey and beer. It is also an intermediate product in the action of dilute sulphuric acid on starch, and of ferments (p. 677) *diastase, saliva, pancreas* on glycogen (p. 662). It can also be obtained from starch paste by means of diastase (A. **220**, 209). It is capable of direct fermentation. It forms a hard, white, crystalline mass.

Reactions.—It was formerly believed that maltose could be directly fermented by yeast. It appears, however, that there is present a second enzyme (glucase ?) which, along with invertin, which does not hydrolyze maltose, decomposes the maltose into dextrose (B. **29**, R. 663). Maltose reduces *Fehling's* solution, but only about two-thirds as much as dextrose, which it resembles very closely (A. **220**, 220).

Diastase does not exert any change on maltose. When boiled with dilute acids, it absorbs water and passes completely into d-dextrose or grape sugar. Nitric acid oxidizes it to d-saccharic acid, whilst chlorine changes it to *maltobionic acid,* $C_{12}H_{22}O_{12}$. This yields dextrose and d-gluconic acid when it is heated with acids. Hydrocyanic acid transforms it into *maltose carboxylic acid*, $C_{12}H_{23}O_{11}.CO_2H$, which decomposes into d-dextrose and d-glucoheptonic acid (A. **272**, 200).

When boiled with lime-water it forms *isosaccharine* (p. 620). *Octacetyl Maltose*, $C_{12}H_{14}O_3(OCOCH_3)_8$, m.p. 156°, yields, with fluid HCl *Heptacetyl Chloromaltose*, $C_{12}H_{14}O_3(OCOCH_3)_7Cl$, m.p. 67°; fuming nitric acid in chloroform solution produces *Heptacetyl Maltose Nitrate*, $C_{12}H_{14}O_3(OCOCH_3)_7(ONO_2)$, m.p. 94°. Both the latter substances react with methyl alcohol to form a *Heptacetyl Methyl Maltose*, m.p 128°, from which the loss of the acetyl groups leaves *β-Methyl Maltose*, $C_{12}H_{21}O_{11}(CH_3)$, m.p. 94° (B. **34**, 4343; **35**, 840). *Maltosazone*, m.p. 206°, is decomposed by benzaldehyde into *maltosone* (B. **20**, 831; **35**, 3142). Maltose is constituted similarly to lactose (p. 660) (B. **22**, 1941).

The following saccharobioses are less important: *Isomaltose*, $C_{12}H_{22}O_{11}$, $[\alpha]_D=+70°$, isomeric with maltose, results from the action of hydrochloric acid on d-dextrose (B. **28**, 3024), and in the mashing process (B. **25**, R. 577; B. **29**, R. 991). Yeast does not ferment it; diastase converts it into maltose; *osazone*, m.p. 150–153°.

Mycose, *Trehalose*, $C_{12}H_{22}O_{11}+2H_2O$ (B. **24**, R. 554; **26**, 1332), occurs in several species of fungi—*e.g.*, in *Boletus edulis* (B. **27**, R. 511), in ergot, and in the oriental *Trehala*. Acids convert it into d-dextrose (B. **26**, 3094).

Melibiose, $C_{12}H_{22}O_{11}$, m.p. 84° (incomplete), $[\alpha]_D^{20}=+129{\cdot}38°$ (C. 1899, II. 526) is prepared from melitriose (see below); it is probably identical with the synthetic galactodextrose (p. 658). It is decomposed by hydrolysis into d-galactose and d-dextrose; *osazone*, m.p. 177° (B. **22**, 3113; **23**, 1438, 3066; **35**, 3146).

Turanose, $C_{12}H_{22}O_{11}$, $[\alpha]_D=+65$ to $+68°$, is formed along with d-dextrose in the partial hydrolysis of melecitose as a white mass; *osazone*, m.p. 215–220° (B. **27**, 2488).

Agavose, $C_{12}H_{22}O_{11}$, is obtained from the stalks of *Agave americana* (B. **26**, R. 189). **Lupeose**, $C_{12}H_{22}O_{11}$, is contained in lupin seeds (B. 25, 2213).

B. TRISACCHARIDES, SACCHAROTRIOSES

Raffinose, *Melitose*, *Melitriose*, $C_{18}H_{32}O_{16}+5H_2O$ (B. 21, 1569, C. 1897, II. 520) $[\alpha]_D=104°$, occurs in rather large quantity in Australian manna (varieties of Eucalyptus), in cotton seed meal, in small amounts in sugar beets, and being more soluble than sucrose, it accumulates in the molasses in sugar manufacture. From this it crystallizes out with the sugar (A. **232**, 173). Its crystals have peculiar terminal points, and show strong rotatory power (*Plus sugar*).

To determine raffinose quantitatively, consult B. **19**, 2872, 3116.

By hydrolysis it yields fructose and melibiose (B. **22**, 1678; **23**, R. 103).

Melecitose, $C_{18}H_{32}O_{16}+2H_2O$, m.p. (anhydrous) 148°, occurs in the juice of *Pinus larix*, and in Persian manna. It is distinguished from sucrose by its greater rotatory power (B. **26**, R. 694), and in not being so sweet to the taste. It decomposes by partial hydrolysis into d-dextrose and turanose (B. **27**, 2488).

Stachyose, $C_{18}H_{32}O_{16}$, is obtained from *Stachys tuberifera* (B. **24**, 2705).

C. POLYSACCHARIDES

The polysaccharides having the empirical formula $C_6H_{10}O_5$, all possess a much higher molecular weight, $(C_6H_{10}O_5)_n$, and differ much more from the hexoses than the di- and tri-saccharides. They are, in general, amorphous and soluble in water, except cellulose, which is insoluble. By hydrolysis, by boiling with dilute acids, or under the influence of ferments (p. 677), nearly all are finally broken up into monoses (see Dextrin). Their alcoholic nature is shown in their ability to form acetyl and nitric esters. They may be classified as *starches, gums* and *cellulose.*

There are certain gums, like cherry gum and wood gum (p. 663) which yield pentoses by hydrolysis. They are, therefore, called *pentosans* to distinguish them from the *dextrosans*—the polysaccharides, which break down into dextroses when they are hydrolyzed (B. **27,** 2722).

On experiments for determining the *molecular magnitude* of the polysaccharides such as starch, glycogen, cellulose, by chemical and physical means, see C. 1906, I. 655, etc.

Starches.—(1) *Starch, Amylum,* $(C_6H_{10}O_5)_n$, is found in the cells of many plants, in the form of circular or elongated microscopic granules, having a definite structure. The size of the granules varies, in different plants, from 0·002–0·185 mm. Air-dried starch contains 10–20 per cent. of water; dried over sulphuric acid it retains some water, which is only removed at 100°. Starch granules are insoluble in cold water and alcohol. When heated with water they swell up at 50°, burst, partially dissolve, and form *starch paste,* which rotates the plane of polarization to the right. The soluble portion is called *granulose,* the insoluble, *starch cellulose.* Alcohol precipitates a white powder—*soluble starch*—from the aqueous solution (C. 1897, II. 842).

One of the supposed main differences between granulose and cellulose in the starch grains appears on closer examination not to exist, since starch is completely soluble at 138°; the starch cellulose is perhaps a reversion product (see p. 658) of the partially hydrolyzed starch. The main constituent of starch, that which is coloured by iodine, and is completely converted by malt into maltose (see below), is known as *amylose,* which is different from the slimy, paste-forming constituent known as *amylopectin* (see Pectin, p. 663) (A. **309,** 288; C. 1905, II. 314; 1906, II. 229).

The blue coloration produced by iodine is characteristic of starch, both the soluble variety and that contained in the granules (B. **25,** 1237; **27,** R. 602; **28,** 385, 783; C. 1897, I. 408, 804; 1902, II. 26). Heat discharges the coloration, but it reappears on cooling. Consult B. **28,** R. 1025, for a quantitative, colorimetric method for the determination of starch.

Boiling dilute acids convert starch into dextrin and d-dextrose (*Kirchhoff,* 1811). When heated at 160–200° it changes into dextrin. Malt diastase changes it to dextrin, maltose, and isomaltose (p. 661) (B. **27,** 293). This is a reaction which is carried out technically on a large scale in the manufacture of alcohol from starch (p. 115).

(2) *Paramylum,* $(C_6H_{10}O_5)_n$, occurs in the infusoria *Euglena viridis.* It is not coloured by iodine, and is soluble in potassium hydroxide.

(3) *Lichenin, Moss-starch,* $(C_6H_{10}O_5)_n$, occurs in many lichens, and in Iceland moss (*Cetraria islandica*). Iodine imparts a dirty blue colour to it. It yields d-dextrose when boiled with dilute acids.

(4) **Inulin** is found in the roots of dahlia, in chicory, and in many Compositæ like *Inula helenium.* Iodine gives it a yellow colour. When boiled with water it is completely changed to d-fructose.

(5) *Carubin,* $(C_6H_{10}O_5)_n$, occurs in St. John's Bread, the pods of *Ceratonia siliqua,* and is decomposed by mineral acids into d-mannose, $C_6H_{12}O_6$.

(6) **Glycogen,** *Liver Starch,* $(C_6H_{10}O_5)_n$, is an important product of metabolism, and occurs in the liver and other portions of mammals;

also in the lower animals and fungi (mushrooms). The liver forms glycogen from dextrose and other monoses, glycerol, formaldehyde, etc. (C. 1907, II. 168; 1908, I. 1176). When boiled with dilute acids glycogen is changed into d-dextrose; ferments, however, produce maltose. For quantitative determination see C. 1899, I. 572; 1903, I. 1305.

The Gums.—These are amorphous, transparent substances widely disseminated in plants; they form sticky masses with water and are precipitated by alcohol. They are odourless and tasteless. Some of them yield clear solutions with water, whilst others swell up in that menstruum and will not filter through paper. The first are called the *real gums* and the second *vegetable mucilages*. Nitric acid oxidizes them to mucic and oxalic acids.

Dextrin, *Starch Gum, Leiocome,* $(C_6H_{10}O_5)_n$.—By this name are understood substances readily soluble in water and precipitated by alcohol; they appear as intermediate products in the conversion of starch into dextrin, *e.g.*, heating starch alone at 170–240°, or by heating it with dilute sulphuric acid. Different modifications arise in this treatment: *amylodextrin, erythrodextrin, achroo-dextrin,* which, however, have received little study (B. **28,** R. 987; **29,** R. 41; C. 1897, I. 408; A. **309,** 288). They are gummy, amorphous masses, of which aqueous solutions are dextro-rotatory, hence the name dextrin. They do not reduce *Fehling's* solution, even on boiling, and are incapable of direct fermentation; in the presence of diastase, however, they can be fermented by yeast (p. 113), and are then converted into d-dextrose. They yield the same product when boiled with dilute acids. The dextrins unite with phenylhydrazine (B. **26,** 2933). The yeast gum present in yeast cells, has been isolated (B. **27,** 925).

Dextrin is prepared commercially by moistening starch with two per cent. nitric acid, allowing it to dry in the air, and then heating it to 110°. It is employed as a substitute for gum (B. **23,** 2104).

Arabin, Gum, exudes from many plants, and solidifies to a transparent, glassy, amorphous mass, which dissolves in water to a clear solution. Gum arabic or gum Senegal consists of the potassium and calcium salts of arabic acid. The latter can be obtained pure by adding hydrochloric acid and alcohol to the solution. It is then precipitated as a white, amorphous mass, which becomes glassy at 100°, and possesses the composition $(C_6H_{10}O_5)_2+H_2O$. It forms compounds with nearly all the bases, which dissolve readily in water.

Some varieties of gum, *e.g.*, gum arabic, yield galactose in considerable quantity when boiled with dilute sulphuric acid; and with nitric acid they are converted into mucic acid; others, like cherry gum, are transformed on boiling with sulphuric acid into l-arabinose, $C_5H_{10}O_5$ (p. 619), and into oxalic acid, not mucic acid, by nitric acid. The gum, extracted from beechwood by alkalis and precipitation with acids, is converted into xylose (p. 619) by hydrolytic decomposition. Hence these gums must be regarded as pentosans (p. 662) (B. **27,** 2722). On the hydrolysis of the pentosans, see also B. **36,** 319).

Bassorin, Mucilage, constitutes the chief ingredient of gum tragacanth, Bassora gum, and of cherry and plum gums (which last also contain arabin). It swells up in water, forming a mucilaginous liquid, which cannot be filtered; it dissolves very readily in alkalis. On the hydrolysis of plant-mucus, see B. **36,** 3197.

Pectin substances (from πηκτός, coagulated) occur in fruit juices, *e.g.*, apple, cherries, currants, greengages, etc. They cause these, under suitable conditions, to gelatinize. They are closely allied to the vegetable gums, and may be regarded as oxymucilage (A. **286,** 278; B. **28,** 2609).

Cellulose, *Wood Fibre, Lignose* $(C_{12}H_{20}O_{10})_x$, possibly $C_{72}H_{120}O_{60}$ (B. **32,** 2507), forms the principal ingredient of the cell membranes of all plants, and exhibits an organized structure. To obtain it pure, plant fibre, or, better, cotton-wool is treated successively with dilute potassium hydroxide solution, dilute hydrochloric acid, water, alcohol, and ether, to remove all admixtures (incrusting substances). Cellulose remains then as a white, amorphous mass.

Sulphite Cellulose is prepared by treating wood with hot calcium bisulphite liquor under pressure, whereby the lignin surrounding the wood fibre is dissolved. Sodium cellulose is formed when straw is heated with sodium hydroxide solution. Cellulose is employed for the manufacture of paper, parchment paper, gun-cotton, smokeless powder, celluloid and celluloid-like bodies, artificial silk, oxalic acid, etc.

Cellulose is insoluble in most of the usual solvents, but dissolves without change in an ammoniacal copper solution (B. **38,** 2798). Acids, various salts of the alkalis and sugar precipitate it as a gelatinous mass from such a solution. After washing with alcohol it is a white, amorphous powder. When acted on by sodium hydroxide solution of various concentrations, cellulose absorbs the alkali with simultaneous contraction. The alkali can be removed by washing with water leaving the cellulose behind as a *hydrate* (*Mercerisation*, B. **40,** 441, 4903). The alkali cellulose combines with carbon disulphide to form water soluble xanthates, known as *viscose* (B. **34,** 1513, etc.), which on hydrolysis also yield *hydrocellulose* or *cellulose hydrates.* These hydration products of cellulose can also be produced in various other ways.

Oxycelluloses constitute a whole series of bodies obtained when cellulose is oxidized by nitric acid, bleaching powder, permanganate, and hydrogen peroxide (B. **34,** 719, 1427, 2415, 3589).

If unsized filter paper be immersed for a short time in sulphuric acid, which has been diluted with half its volume of water, and then washed with water there is formed *parchment paper* (vegetable parchment) which is similar to parchment, and has many uses. In concentrated sulphuric acid cellulose swells and dissolves to a paste from which water precipitates a body similar to starch (amyloid), which is coloured blue by iodine. Prolonged action of sulphuric acid produces *dextrin,* which is converted into racemic acid by dilution and subsequent boiling. Sulphuric acid and acetic anhydride produce an acetoacetate of a saccharobiose, the crystalline *cellobiose,* $C_{12}H_{22}O_{11}$, *osazone,* m.p. 198°. This, which can be obtained from the acetate by hydrolysis with potassium hydroxide, yields in part on hydrolysis with dilute sulphuric acid, dextrose. Cellobiose stands in the same relation to cellulose as maltose to starch (B. **34,** 1115; C. 1902, I. 183; comp. I. 1902, I. 405).

Nitrocelluloses.—Strong nitric acid produces from cellulose, first, a hydrolyzable *nitrate* (B. **37,** 349; C. 1908, I. 2024). A more concentrated acid, or, better, a mixture of nitric and sulphuric acids forms *nitric esters,* known as *nitrocelluse* (C. 1901, II. 34, 92; B. **34,** 2496).

According to the mode of action, the products show varying characteristics. If pure cotton wool is immersed for 3–10 minutes in a cold mixture of 1 part of nitric acid with 2–3 sulphuric acid, and then carefully washed with water, there is formed *gun-cotton* (pyroxylin), which was discovered in 1845 by *Schönbein*. It is insoluble in alcohol and ether and their mixture, and explodes violently when ignited in a closed space by percussion. In the air it burns very rapidly without exploding. If the cotton wool be immersed for a longer time in a warm mixture of 20 parts of powdered sodium nitrate and 30 of concentrated sulphuric acid, there is formed *soluble pyroxylin,* which is dissolved by a mixture of ether and a little alcohol. The solution is known as *collodion* ; this, on evaporation, leaves the pyroxylin in the form of a thin transparent skin insoluble in water, which is employed in surgery and photography.

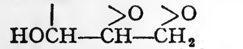
The explosive insoluble gun-cotton consists mainly of *cellulose hexanitrate,* $C_{12}H_{14}(O.NO_2)_6O_4$, whilst the ether-alcohol soluble pyroxylin is formed chiefly of the tetranitrate, $C_{12}H_{16}(ONO_2)_4O_6$, and the pentanitrate, $C_{12}H_{15}(O.NO_2)_5O_5$ (B. **13,** 186). The solution of collodion cotton in nitrogylcerine (with small quantities of other substances), constitutes a blasting gelatin which is employed as *smokeless powder* (B. **27,** R. 337).

When mixed with camphor, nitrocellulose forms *celluloid,* a substance like *vulcanite* (highly vulcanized rubber), having the disadvantage of burning violently when ignited.

Acetyl Cellulose is formed by the action of glacial acetic acid, acetic anhydride, and a small quantity of concentrated sulphuric acid, or zinc chloride on cellulose. It is characterized by its solubility in various organic solvents and insolubility in water. It is used, like ammonium-copper hydroxide cellulose (p. 664) and nitrocellulose, for the preparation of *artificial silk,* and many other technical purposes (C. 1902, II. 1022 ; 1907, I. 1736 ; 1908, I. 1831).

Simultaneous action of acetic anhydride and nitric acid produces *cellulose acetonitrate* (B. **41,** 1837). Formic acid and sulphuric or hydrochloric acid give rise to *cellulose formate* (C. 1908, I. 328). Benzoyl chloride and pyridine produce *benzoyl cellulose* (C. 1903, I. 744).

It is remarkable that it has been found impossible to introduce more than three acyl, NO_2, CH_3CO, etc., groups into cellulose, of which the simplest formula is $C_6H_{10}O_5$ (C. 1906, II. 672). This, together with the ease with which cellulose is converted by HCl or HBr into bromo- and chloro-methyl furfural (Vol. II.) suggests as the simplest formula



$$\begin{array}{l} \mathrm{HO.CH{-}CH{-}CH{-}OH} \\ \quad\ |\qquad >O\ >O \\ \mathrm{HOCH{-}CH{-}CH_2} \end{array}$$

(C. 1906, II. 321), of which 12 polymers of cellulose become possible.

The products of dry distillation of wood, such as acetic acid, acetone, and methyl alcohol, are the most important decomposition-products of cellulose. When fused with alkali, cellulose similarly yields oxalic acid (p. 480). Fermentation of cellulose causes the formation of CO_2, hydrogen and methane (C. 1904, I. 1338 ; 1906, I. 1034, etc.).

ANIMAL SUBSTANCES OF UNKNOWN CONSTITUTION

Now that the description of the aliphatic bodies has been concluded, certain substances of animal origin will be mentioned, of which exhaustive treatment properly belongs to the province of physiological chemistry. It is especially noteworthy that very frequently well-known mono- and di-amino-acids and hydroxyamino-acids of the aliphatic series are found among the decomposition products of these bodies. Many of the substances described in the following pages occur, both in the vegetable and animal kingdoms, in closely related modifications of uncertain constitution, *e.g.*, the *proteïns*, the *nucleïns*, the *cholesterols*, the *enzymes*, etc., and also the *carbohydrates* (p. 656) and *lecithins* (p. 531), which have already received mention.

PROTEÏNS, ALBUMINS [*]

These were formerly known as proteid substances, and form the principal constituents of the animal organism. They also occur in plants (chiefly in the seeds), in which they are exclusively produced. When absorbed into the animal organism as nutritive matter they undergo but very slight alteration in the process of assimilation.

The composition of the different proteïns varies within definite limits (J. pr. Ch. [2] **44**, 345):

C	50·0	to	55·0 per cent.	Crystallized Albumin:	C	51·48	per cent.
H	6·9	,,	7·3 ,,		H	6·76	,,
N	15·0	,,	19·0 ,,		N	18·14	,,
O	19·0	,,	24·0 ,,		O	22·66	,,
S	0·3	,,	2·4 ,,		S	0·96	,,

The molecular magnitude of the proteïns is not definitely known. There is no doubt but that their molecular weights are large. *Sabanejeff*, employing *Raoult's* method, obtained 15,000 for the molecular value of purified egg albumin. All proteïns rotate the plane of polarization to the left. They always leave an inorganic residue when they are burned. In the solution and precipitation processes employed in obtaining them free from mineral ash, the proteïn frequently undergoes a change in its properties (B. **25**, 204).

When the proteïns are oxidized, there are formed volatile fatty acids and their aldehydes, ketones and nitriles, hydrocyanic and benzoic acids. Permanganate produces first oxyprotosulphonic acid, of the composition C=51·21 per cent., H=6·89 per cent., N=14·59 per cent., S=1·77 per cent., O=25·54 per cent.; and finally peroxyproteïc acid C=46·22 per cent., and H=6·43 per cent., N=12·30 per cent., S=0·96 per cent., O=34·09 per cent. (Z. physiol. Ch. **19**, 225).

Boiling with dilute sulphuric or hydrochloric acid, or with barium hydroxide solution or other alkalis, produces mainly amino-acids, the *simplest decomposition products of the proteïns*, with varying quantities of ammonia and carbon dioxide. The most important of the acids, of which the structural formulæ can be ascertained are:

a. **Monamino-monocarboxylic Acids.**

Glycocoll, $NH_2CH_2CO_2H$ (p. 385). *Hippuric Acid*, $C_6H_5CONH.CH_2CO_2H$ (Vol. II.).

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[*] Die Eiweissarten der Getreidearten, Hülsenfrüchte und Oelsamen, von *H. Ritthausen*, 1872. Handbuch der physiologisch- und pathologisch-chemischen Analyse, von *F. Hoppe-Seiler*, 1893. "Eiweisskörper," Artikel von *Drechsel* in *Ladenburg's Handw.*, 1885. *R. Neumeister*, Lehrbuch der physiol. Chemie, Aufl. II., 1897. *Hammarsten*, Lehrbuch der physiol. Chemie, Aufl. IV., 1899. *A. Kossel*, Über den gegenwärtigen Stand der Eiweisschemie, B. **34**, 3214; ***E. Fischer***, Untersuchungen über Aminosäuren, Polypeptide und Proteïne, 1906.

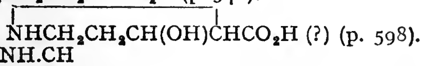
Alanine, $NH_2CH(CH_3)CO_2H$ (p. 388).
Valine, $NH_2CH[CH(CH_3)_2]CO_2H$ (p. 389).
Leucine, $NH_2CH[CH_2CH(CH_3)_2]CO_2H$ (p. 389).
Isoleucine, $NH_2CH[CH(CH_3)(C_2H_5)]CO_2H$ (p. 390).
Phenyl Alanine, $NH_2CH(CH_2C_6H_5)CO_2H$ (Vol. II.).
Tyrosine, $NH_2CH[CH_2[1]C_6H_4[4](OH)]CO_2H$ (Vol. II.).

Tryptophane, 
$NH_2CH[CH_2.C{<}\genfrac{}{}{0pt}{}{C_6H_4}{CH}{>}NH]CO_2H$ (Vol. II.).

b. **Monamino-dicarboxylic Acids.**
Aspartic Acid, $NH_2CH(CO_2H)CH_2CO_2H$ (p. 553).
Glutaminic Acid, $NH_2CH(CO_2H)CH_2CH_2CO_2H$ (p. 558).

c. **Hydroxamino-, Thioamino-, Diamino-, Imino-Acids.**
Serine, $HOCH_2.CH(NH_2)CO_2H$ (p. 540).
Cystine, $NH_2CH(CO_2H)CH_2S.SCH_2CH(NH_2)CO_2H$.
Ornithine, $NH_2CH_2CH_2CH_2CH(NH_2)CO_2H$, together with *Arginine,* $NH_2C(NH)$-$NH.CH_2CH_2CH_2CH(NH_2)CO_2H$, and *Ornithuric Acid,* $C_6H_5CONHCH_2CH_2CH_2$-$CH(NH_2)CO_2H$ (p. 542).
Lysine, $NH_2CH_2CH_2CH_2CH_2CH(NH_2)CO_2H$ (p. 542).

Proline, 
$NHCH_2CH_2CH_2CHCO_2H$ (p. 542).

Hydroxyproline, 
$NHCH_2CH_2CH(OH)CHCO_2H$ (?) (p. 598).

Histidine, 
$CH{<}\genfrac{}{}{0pt}{}{NH.CH}{N—C—CH_2CH(NH_2)CO_2H}$ (comp. p. 546).

All these products are not obtained from all proteïns, and their relative quantities vary within wide limits according to the various parent proteïns. The quantitative separation of each amino-acid from a mixture of decomposition products has until now only been effected imperfectly, either by precipitation methods (comp. p. 669) or by *E. Fischer's* method of esterifying the acid mixture, and separating the esters by fractional distillation in vacuo (p. 49).

The hydrolytic decomposition of proteïns is carried out most quickly by mineral acids, and less well by alkalis; further, the same effect is achieved by means of the ferments of the alimentary canal such as *pepsin* and *trypsin,* whereby the proteïn passes through a series of intermediate products—albumoses, peptones, poly- and di-peptides (comp. pp. 390, 670) before the amino-acids are reached. The mineral acid hydrolysis can be carried out so that the poly- and di-peptides can be collected (B. **40,** 3544).

The life processes of lower organisms such as the bacilli, bacteria, etc., concerned in putrefaction break down the proteïns into fatty acids up to caproic acid, *δ-aminovaleric acid* (p. 389) (B. **24,** 1364); *phenyl acetic acid,* $C_6H_5CH_2CO_2H$ (Vol. II.); p-*hydroxyphenyl propionic acid,* $HO[4]C_6H_4[1]CH_2CH_2CO_2H$ (Vol. II.); *phenol,* C_6H_5OH (Vol. II.); also *β-indole propionic acid, indole acetic acid, skatole* (*β*-methyl indole), *indole*—bodies which are produced by the breaking down of tryptophane (see above) similarly to the previously mentioned from phenyl alanine and tyrosine (formula, see above, and B. **37,** 1801; **40,** 3029). Other basic substances are also formed during putrescence, mainly diamines and imines of the fatty series, known as *ptomaines* and *toxins* (p. 331).

Certain pathogenic organisms, such as the diphtheria and anthrax bacilli, produce a less far-reaching basic decomposition (?) whereby poisonous proteïn and peptone-like bodies are formed known as *toxalbumins,* which, when heated in aqueous solution lose their poisonous properties (B. **23,** R. 251).

Proteïns are produced in plants in daylight by unknown means from CO_2, H_2O, NH_3, HNO_3 and H_2SO_4; plants containing chlorophyll also use substances containing the groups —CH_2— and —CHOH—.

A knowledge of the constitution of the proteïns can only be formed from a few general aspects.

The decomposition products show that the major part of the carbon is aliphatic. Also the proteïn yields only a relatively small quantity of break-down products possessing the aromatic ring, such as phenyl alanine, tyrosine, tryptophane, as well as phenol, skatole and indole (B. **12,** 652, 1987).

Potassium or barium hydroxide solution expels various quantities of N as NH_3

(up to ⅓) according to the kind of proteïn, and length of time of boiling (C. 1867, 385; *Pflüger's* Arch. **6,** 606; Z. physiol, Chem. Ch. **29,** 51).

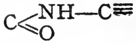
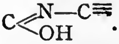
When boiled with hydrochloric acid, about $\frac{1}{10}$ of the N separates as NH_3, ⅔ to ¾ as amino-acid, whilst the rest is obtained as bases precipitated by phosphotungstic acid (Z. physiol. Ch. **27,** 105; **29,** 47).

Nitrous acid drives out about $\frac{1}{10}$ of the proteïn nitrogen as gas (B. **29,** 1354). Thus the large quantities of amino-acids formed by hydrochloric acid are not previously formed, but are produced by hydrolytic decomposition, especially the NH_2-groups.

Since pepsin digestion constitutes a mild form of hydrolysis, the proteïns acted on by this reagent yield ⅓ of their nitrogen as N_2 when treated with nitrous acid, but give no nitroso-reaction—the :NH group is absent. Proteïn thus digested and treated with nitrous acid yields aminocaproic acid when boiled with dilute sulphuric acid, whereby the amino-group can only be called into being by the hydrolysis (J. pr. Ch. [2] **31,** 134, 142).

Since glutin-peptone is a decomposition product of proteïn in which the nitrogen occurs in primary, secondary, and tertiary combination (B. **29,** 1084), the above discussed facts hold good for proteïn also. When it has been shown that the NH_2-group occurs only in small numbers in the proteïn molecule, the larger part of the nitrogen must occur in secondary and tertiary form. The latter, in particular, must unite together the groups of atoms from which hydrolysis produces amino acids.

The sulphur present in proteïns can be separated up to about one-half as potassium sulphide, by boiling with alkalis in absence of oxygen; whilst the other half can be found as sulphuric acid when the substance is fused with sodium nitrate and hydroxide, but it is uncertain whether oxidation has taken place (Z. physiol. Chem. **25,** 16). Probably the main portion of the sulphur is contained in proteïns as an atomic complex of cystine (p. 667).

Oxygen is found in the decomposition products other than that in the phenol-hydroxyl of tyrosine, and the alcoholic hydroxyl in serine and hydroxyproline (p. 677), mainly in the carboxyl groups of the amino acids. Therefore, in the proteïn it must exist as COOH, $CONH_2$ and  $\mathrm{C}{<}^{\mathrm{NH—C}\equiv}_{=\mathrm{O}}$ or  $\mathrm{C}{<}^{=\mathrm{N—C}\equiv}_{\mathrm{OH}}$.

Moreover, proteïn is found united with sugar (or hexosamine, such as dextrosamine), p. 636, forming glucoproteïns. If the sugar is split off by the action of acids, the proteïn is obtained with all its characteristic properties (*Pflüger's* Arch. **65,** 281; C. 1899, I. 687; comp. B. **34,** 3241).

It is so far quite unknown how the larger groups of atoms which are found as decomposition bodies, are arranged in space in the proteïn molecule.

The physiological significance of the proteïns lies mainly in the fact that they supply the material from which cell-substance is built. Here the proteïn is sometimes, perhaps always, in chemical combination with other inorganic and organic molecules.

It is also remarkable that proteïn is the only substance which, with water and salt alone, and without fat and carbohydrates, can preserve animal life; it can only partially be replaced by fats and carbohydrates. However copious may be the supply of food, it will not preserve life if it does not contain a certain quantity of proteïn substances. The energy of an animal increases with the content of proteïn in a mixed diet.

Like the fats and carbohydrates, ordinary proteïn is quite indifferent to atmospheric oxygen, in the absence of ferments. Since the intensity of oxidation exerted by the living organism, *i.e.*, by the cell-substance, is quite independent of the fat and carbohydrate content but very dependent on the nitrogen content, the conclusion has been drawn that proteïn changes its composition on becoming a constituent of cell-matter, and becomes "active" to oxygen, comparably to yellow phosphorus among the inorganic substances. In other words, there is a vast difference between dead and living proteïns (*Pflüger*, arch. **6,** 43; **10,** 251, 641; **11,** 222; **12,** 282, 333; **14,** 1, 630; **18,** 247; **19,** 166; **51,** 229, 317; **52,** 1, 239; **54,** 333; **77,** 425).

Finally, proteïn establishes its peculiar position in animal metabolism by the fact, that in the nourishment of the living animal the proteïn is *first* and completely oxidized, and that the fat and carbohydrate are only attacked when the quantity of proteïn matter is not sufficient. Thus, the proteïn metabolism increases within definite limits proportionally to its supply and quite independently of the supply of fat and carbohydrate; an increase in fat and carbohydrate has no deep influence on the former (*Pflüger*, etc.).

The nitrogenous derivatives of proteïn, which are eliminated in the urine, cannot in general be obtained artificially. The living organism converts proteïn by oxidation and cleavage into ammonium salts, which become synthesized mainly in the liver, to urea, uric acid, and other amido-bodies.

The proteïns are usually insoluble in water. Their presence in the juices or fluids of the living organism is entirely due to the presence of salts and other substances which are still unknown. They are insoluble in alcohol and ether; most of them are precipitated on boiling in weak acetic acid solution, by acetic acid and potassium ferrocyanide, or acetic acid and sodium sulphate, and by certain mineral acids, as well as by salts of the heavy metals; also, by phosphotungstic acid, phosphomolybdic acid, potassium mercury iodide and potassium bismuth iodide, all in the presence of mineral acids; further, by acetic and tannic or picric acids, trichloracetic acid, sulphosalicylic acid, taurocholic acid, nucleïc acid, and chondroïtin-sulphuric acid; finally, by alcohol in neutral or weakly acid solution.

Many proteïns are separated from solution by boiling, by alcohol, by mineral acids, etc: they are *coagulated*. Their solubility is entirely changed. This is not the case with the so-called *propeptones*, which when precipitated by alcohol dissolve after the removal of the latter as readily in water as before the precipitation.

Reactions.—All proteïns are coloured a violet-red, like tyrosine, when warmed with a mercuric nitrate solution containing a little nitrous acid (*Millon's* reagent). A yellow colour is produced when they are digested with nitric acid, which becomes a golden yellow on neutralization with ammonia (*Xanthoproteïn reaction*). The proteïns yield beautiful violet-coloured solutions when digested with fuming hydrochloric acid. Potassium hydroxide solution and copper sulphate also impart a red to violet coloration to proteïn solutions (*Biuret reaction*) (B. **29**, 1354). On the addition of sugar and concentrated sulphuric acid they acquire a red coloration, which on exposure to the air becomes dark violet. If concentrated sulphuric acid be added to the acetic acid solution of proteïns they acquire a violet coloration and show a characteristic absorption band in the spectrum.

The manner of distinguishing and classifying the various proteïns is yet very uncertain. The original proteïns, occurring in nature, are albumin, globulin, caseïn, gluten proteïns, etc., whilst the secondary modifications obtained from them through the agency of chemicals or ferments are: acidalbumins, albuminates, coagulated albumins, fibrins, propeptones, peptones, etc.

Many of these modifications result from the breaking-down of the molecule of the original proteïn. It is well worth noting in such instances that the decomposition product still maintains the essential character of the proteïns just as the starch molecules yield molecules of dextrose, which, like the starch, continue as carbohydrates. The breaking-down of the original proteïn, in the reactions referred to, is proved by a fall in molecular weight. This has been partly determined by the method of Raoult (p. 16) and in part by testing the electric conductivity. The decomposition is also evidenced by the fact that the proportion of the carbon to the nitrogen in the decomposition product frequently varies from that in the other decomposition product, just as much as it varies between these substances in the parent body (*Schmiedeberg*, Arch. exp. Path. **39**). This decomposition of the proteïn molecule is a hydrolytic decomposition. **See** Proteïns, p. 666.

In a certain number of secondary proteïn modifications ammonia, sulphur, and amido-acids, like leucine and tyrosine, etc., have been split off, without the loss of the essential character of the proteïn.

Of pre-eminent importance is the fact that the organs of the living animal body have the power of synthesizing the original proteïn from the products with lower molecular weights. This is certainly similar to the formation of glycogen (p. 662)—the animal starch, from dextrose, in the liver.

1. **Albumins,** *soluble in water,* dilute acids and alkalis, dilute and saturated solutions of sodium chloride or magnesium sulphate. In the presence of acetic acid the albumins are completely precipitated by saturation with sodium chloride, magnesium or ammonium sulphate. When heated with sodium hydroxide solution there is produced the sodium salt of the water-insoluble *protalbic acid,* and the water-soluble *lysalbic acid* (B. **35,** 2195). When heated in presence of neutral salts, the albumins, including serum-, egg-, and lact-albumin, are coagulated.

2. **Globulins,** *insoluble in water,* but soluble in dilute solutions of sodium chloride and magnesium sulphate. These solutions are coagulated on boiling, and by saturated solutions of ammonium or magnesium sulphates at 30°, which precipitate them without any alteration in properties. This class contains: **myosin** and **musculin** (muscles), **fibrinogen** (in the living blood converted to fibrin by the fibrin ferment); **fibrin-globulin; serum-globulin; crystal-lens globulin** and **vitellin**; also the proteïns of the seeds of plants, especially **edestin,** which forms a crystalline calcium and magnesium salt, and which has been more thoroughly examined.

3. The **Gluten Proteïns** are characterized by their physical properties. In the hydrous state they are pasty, elastic masses. They only occur in wheat flour, where they constitute the chief essential for bread-making. Gluten is insoluble in water, and sparingly soluble in water containing a very little dilute acid or alkali. Its solubility in alcohol (60–70 volume per cent.) is very characteristic. Some gluten proteïns when decomposed yield large quantities of glutaminic acid. Thus, *Ritthausen* obtained not less than 25 per cent. of glutaminic acid from **mucedin** (see *Ritthausen,* etc., p. 222). Possibly the liver-proteïns are proteïns modified by ferments.

4. **Acid Albumins** or **Syntonins** are *insoluble in water* and salts, soluble in hydrochloric acid or a soda solution, *do not expel carbon dioxide* from calcium carbonate, and are precipitated in *acid* solution by neutral metallic salts of the alkalis and alkali earths. Alkali hydroxide converts them into albuminate. The acid albumins are produced on treating the albumins, globulins, etc., with hydochloric acid, or with other acids (B. **28,** R. 858).

5. **Albuminates,** *insoluble in water* and salts, readily soluble in dilute acids (but precipitated by an excess) and a soda solution, *expel carbon dioxide* from calcium carbonate. They can be precipitated without alteration from acid, as well as *alkaline,* solutions by saturation with solutions of neutral salts of the alkalis and alkali earths. The albuminates are produced when albumin, globulin, etc., are treated with alkali hydroxide (see above, Protalbic and Lysalbic acids). They cannot be changed by mineral acids into acid albumins, and the compound from acid albumin and alkali is not an alkali albuminate. The modifications produced by treatment with mineral acids and alkalis are quite different bodies.

6. **Coagulated Albumins.**—They are insoluble in water and salt solutions, and scarcely soluble in dilute acids. They are obtained by heating other albumins, or by the addition of alcohol, certain mineral acids and metallic salts.

7. **Fibrins,** *insoluble in water,* scarcely soluble in sodium chloride solution, and in other salts, or in dilute acids, formed from globulin by a ferment (*thrombin*) in discharged blood. The process of blood coagulation is expressed according to the investigations of *Schmiedeberg* (Arch. exp. Path. **31,** 8) by the following equation:

$$\underset{\text{Fibrinogen.}}{(C_{111}H_{168}N_{30}SO_{35})_2}+H_2O=\underset{\text{Fibrin.}}{C_{108}H_{162}N_{30}SO_{34}}+\underset{\text{Fibrinoglobulin.}}{C_{114}H_{176}N_{30}SO_{37}}.$$

8. **Propeptones or Albumoses** (B. **29,** R. 518). Enzymes of the gastric and pancreatic juices produce modifications of the proteïns by hydrolytic digestion, whereby the proteïn passes through a series of changes—from the water-insoluble condition to that soluble in water containing neutral salts or even in pure water,

but still precipitated by nitric or acetic acids and potassium ferrocyanide, and finally not even by these. The albumoses cannot be separated from the mixture either by neutralization or by boiling, but are completely precipitated by a saturated solution of ammonium sulphate containing a little acetic acid. The following is noteworthy :—

"The albumoses cannot be coagulated either by boiling their neutral or acidified aqueous solutions, nor by the prolonged action of alcohol upon them, although they are insoluble in strong alcohol, and are precipitated by the latter." * Prolonged digestion converts them finally into—

9. **Peptones,** which are perfectly soluble in water, acids, alkalis and salts of the light metals. They cannot be separated from their solutions either by heat, nitric acid, by acetic acid and potassium of ferrocyanide, or by ammonium sulphate. Phosphotungstic acid precipitates the peptones in the presence of hydrochloric acid ; mercuric chloride, basic lead acetate, alcohol, etc., incompletely.

Proteïns, when acted on by *pepsin* and dilute hydrochloric acid at 30–40°, are dissolved, completely digested, and at first are converted into *syntonins* or *acid albumins,* then into *albumoses* or *propeptones,* and finally into *peptones,* which dissolve readily in water, are not coagulated by heat, and are not precipitated by most reagents (B. **16,** 1152 ; **17,** R. 79). For the molecular weight and constitution of the peptones consult B. **25,** R. 643 ; **26,** R. 22. The lowering of molecular weight of the proteïn molecule by digestion, indicates that it has been broken down. That hydrolysis has taken place is most clearly shown by the action of nitrous acid which evolves much less nitrogen from proteïns than from the albumoses or peptones ; and also by obtaining by boiling with acids without ferments, or by merely heating in presence of water, the same bodies as by digestion (see p. 667). Further, the pancreatic enzyme and the ferments of putrescence also produce true peptones from proteïns. The gastric enzyme does not act in neutral solution, contrary to that of the pancreas, which not only converts proteïns to peptones (like the gastric ferment) but also splits them into amino acids and bases (*Hedin, Dubois-Reymond's* Arch. 1891, 273 ; *Kutscher,* Z. physiol. Ch. **25,** 195 ; *Kossel,* Z. physiol. Ch. **25,** 194). It is therefore noteworthy, that in the case of carnivors, at any rate, the purely meat portion of the food is only dissolved in the stomach (*Pflüger's* Arch. **77,** 438).

The artificially *synthesized di-* and *polypeptides* which have already been discussed (pp. 390, 543, 555) resemble the peptones, in that many of them are broken down by pancreatic juice to the simpler amino-acids, as happens with the peptones themselves.

There exists a whole series of bodies more or less closely connected with the proteïns. Some are even more complicated than the proteïns themselves because they are compounds of them ; others possess the characteristics of the more or less decomposed proteïn molecule.

A. GLUCOPROTEÏNS

These bodies yield proteïns and sugar or aminocarbohydrates when boiled with mineral acids (*Eichwald,* A. **134** ; *Pavy,* The Physiology of the Carbohydrates, tr. into German by K. Grube, 1895, *Hofmeister,* Z. physiol. Ch. **24,** 169 ; *Müller* and *J. Seemann,* Deutsche med. Wochenschr., 1899, m. 13 ; *Seemann,* Arch. J. Verdauungskrankheiten, IV. 1898).

They are sub-divided into—

(1) The *glucoproteïns,* which almost completely resemble the true sugar-free proteïns in elementary composition and in all reactions, and which includes ovalbumin of birds' eggs (*Hofmeister,* Z. physiol. Ch. **24,** 169). This group is not absolutely established, partly because of the impurity of the parent substances, and because a solution of the ovalbumin can be crystallized out from the dextrose compound (ovomucoïd) ; partly because such trustworthy chemists as *K. Mörner* or *Spenzer* could not obtain a sugar from *purified* ovalbumin ; and partly because the glucoproteïns almost completely resemble the sugar-free proteïns in elementary composition and all other reactions.

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* Lehrbuch der phys. Chemie von R. Neumeister, S. 229 (1897).

(2) The *Mucins* are poorer in carbon and particularly in nitrogen, and are richer in oxygen than the glucoproteïns, probably on account of their larger sugar content. They are not coagulated when boiled in neutral or weakly alkaline solution; nor by acetic acid and potassium ferrocyanide in presence of sodium chloride; but are precipitated by an excess of acetic acid. They form ropy solutions.

(3) The *chondroglucoproteïns* are compounds of proteïn or gum with chondroïtin sulphuric acid (p. 673).

(4) The *Mucoïds, Mucinogens* and *Hyalogens* include a large number of substances which belong to this section, such as ovomucoïd, pseudomucin of the ovarial cysts, etc., but which have only been investigated to a small extent.

B. PHOSPHORPROTEÏNS

These bodies consist of proteïns with which phosphoric acid is combined in a peculiar manner.

(1) The *Nucleïns*. When various cell-substances are dissolved with gastric juice there remains behind the insoluble cell nucleus (*Meischer, Hoppe-Seyler's* Med.-chem. Untersuchung, p. 451). This is *nucleïn*, which can be purified by solution in dilute alkalis, precipitation with dilute acids and final washing with alcohol and ether. Boiling mineral acids or alkalis split the nucleïns into albumin and *nucleinïc acid*. This is further decomposed when boiled with mineral acids into phosphoric acid, uracil bodies (see uracil, crytosine, thymine, p. 574), purine bases (see xanthine, guanine, adenine, hypoxanthine, p. 587), and other bases not clearly recognized. According to *Liebermann*, nucleïn contains metaphosphoric acid (B. **21**, 102). Some nucleïns yield carbohydrates on decomposition, such as hexoses and pentoses (comp. l-Xylose, p. 619). (See constitution of thymus nucleïc acid, B. **41**, 1905.) Nucleïc acid and albumin in acid solution give a precipitate, which is included among the nucleïns (Z. physiol. Ch. **22**, 80).

(2) *Para-* and *pseudo-nucleïns* are differentiated by their yielding albumin and phosphoric acid, but no purine bases when boiled with mineral acids. They can be artificially prepared by the action of metaphosphoric acid on albumin (*Pflüger's* Arch. **47**, 155; B. **21**, 598). The proteïns remaining insoluble after the action of pepsin on paranucleïns, are known as *nucleo-albumins*, to which class milk-caseïn belongs.

Caseïn is dissolved in milk in the form of a salt containing the percentage composition of a proteïn with 0·85 per cent. of phosphorus. It is precipitated by dilute acids, as it is insoluble in water. Solution in alkalis and precipitation by acids is employed for its purification. Sodium chloride or magnesium sulphate precipitates it from its solution without change, and it can be purified by a repetition of this process. Decomposition of caseïn with concentrated hydrochloric acid leads to the formation of all the hydrolytic decomposition products referred to on p. 677, together with *diamino-trihydroxy-dodecanoic acid* (*E. Fischer*, l.c. p. 736). For *chlorocaseïn* and its decomposition product, see C. 1901, II. 690).

A solution of the alkali or calcium salt of caseïn does not coagulate when heated.

A calcium-free solution of caseïn is not coagulated by rennet, but coagulation occurs on the addition of a calcium salt, even after the rennet has been rendered inactive by boiling. Rennet probably causes a decomposition of the caseïn into proteïn which is precipitated (paracaseïn) and a soluble proteïn (milk albumin).

The paranucleïn which is left behind after the action of gastric juice on caseïn is finally completely dissolved (*Salkowsky, Pflüger's* Arch. **50**, 225).

That portion of the caseïn molecule with which the phosphoric is combined is attacked only with difficulty during hydrolytic decomposition; so that at a certain period during reaction, this behaves as a paranucleïn, and would be called a true nucleïn if it also contained xanthine bases.

The following class of substances have much in common, though to a diminished extent, with the decomposition products of the proteins.

C. GELATIN (DERIVATIVES OF INTERCELLULAR MATERIALS)

Certain nitrogenous animal tissues, when boiled with water yield *glutins*, and form the major portions of the intercellular substances—they are true collagens.

That they are formed from albumin is shown by their absence in birds' eggs before incubation, and their first appearance in the embryo; also, by the young of herbivorous animals which take only milk (which contains no gelatin), still continuously producing large quantities of collagen tissue.

Glutin, *Gelatin, Bone Glue,* swells in cold water, and dissolves on boiling to a sticky liquid, which gelatinises again on cooling. Concentrated acetic acid or boiling dilute sulphuric acid destroys this power of setting (*fluid glue*).

Gelatin has approximately the elementary composition of the proteïns, except that it contains less sulphur. It rotates the plane of polarization to the left. Solutions of gelatin are precipitated by acetic acid and sodium chloride or potassium ferrocyanide (excess of the latter, however, redissolves it), also by mercuric chloride and hydrochloric acid or sodium chloride, by metaphosphoric or phosphotungstic acid and hydrochloric acid, or potassium mercury iodide and hydrochloric acid, or by saturation with ammonium sulphate.

Tannic acid precipitates gelatin tannate as a yellow sticky precipitate. It also combines with substances which yield gelatin, and forms *leather*. Gelatin solutions give the *Millon* and biuret reaction; also a feeble xanthoproteïn colour.

Dry distillation of gelatin gives rise to the formation of pyrrole and pyridine bases (bone oil). Oxidation with permanganate produces *oxamide* (which also results from other proteïns) and guanidine (from arginine, p. 667); and, with acid hydrogen peroxide, acetone and isovaleraldehyde (probably from leucine) (C. 1902, II. 340).

When gelatin is boiled with concentrated hydrochloric acid the same decomposition products are obtained as from albumin—glycocoll (about 16·5 per cent.) leucine, proline, oxyproline, also serine, aspartic acid, glutaminic acid, alanine, phenylalanine, arginine, etc. (*E. Fischer*, l.c. pp. 671, 680, 739), but no tyrosine and tryptophane, and in the case of putrescence, no tyrosine, indole and skatole.

Gentle action of hydrochloric acid produces the alcohol-soluble *glutin-peptone hydrochloride*. The action of nitrous acid on the glutin peptone shows that it contains primary and secondary, as well as tertiary amino groups (B. **29**, 1084). Longer action of approximately a 12 per cent. hydrochloric acid solution gives rise to *glutokyrine* (a glutin-peptone), which appears to be formed, together with glutaminic acid and glycocoll, from arginine and lysine (C. 1903, I. 1144). Tryptic digestion of gelatin produces a dipeptide anhydride *prolyl glycine anhydride* (p. 543) (comp. B. **40**, 3544).

Although gelatin is very similar to albumin in its composition, it cannot replace it in animal metabolism.

According to the substitution of calcium and magnesium salts, fat, etc., into those tissues which can supply gelatin, bone-fat and cartilage result.

"The cartilage-gelatin, or *chondrin* of some authors, obtained by boiling ordinary cartilage, consists of a mixture of gelatin, and certain compounds of chondroïtin sulphuric acid with gelatin- or proteïn-like substances on the one hand and alkalis on the other" (*Schmiedeberg*, Arch. exp. Pathol. u. Pharmakol. **28**; Mörner, see p. 655, footnote; *Hammarsten*, p. 322).

Chondroïtin Sulphuric Acid is, in its structural details, a still unelucidated condensation product of sulphuric acid, acetic acid, and a polysaccharide amide or its corresponding acid (A. **351**, 344). An artificial mixture of gelatin and chondroïtin sulphuric acid salts give the reaction of *chondrin*. *Amyloid*, which appears pathologically in concentrically arranged layers of grains, and in the arterial walls, belongs to the chondroproteïns, and also contains chondroïtin sulphuric acid.

Chitin is the chief compound of the shells of crabs, lobsters, and other articulates. *Krawkow* (Z. f. Biol. **29**, 177) considers that the chitin in shells is combined with a proteïn-like substance, and occurs in various modifications. It is noteworthy that here also the nitrogen is contained as *dextrosamine* (p. 636), since the cleavage of chitin by hydrochloric acid yields dextrosamine and acetic acid (*Ledderhose*, Z. physiol. Ch. **2**, 224). In that case the equation should hold (*Schmiedeberg*, etc.):

$$\underset{\text{Chitin.}}{C_{18}H_{30}N_2O_{12}}+4H_2O = \underset{\text{Dextrosamine.}}{2C_6H_{13}NO_5}+\underset{\text{Acetic Acid.}}{3CH_3CO_2H}.$$

When chitin is fused with potassium hydroxide at 184° it is converted into acetic acid and *chitosan*, which, when heated with hydrochloric acid is split up into acetic acid and dextrosamine (B. **28**, 32). The stiffening material of fungi is probably identical with chitin, so that the *mycosin*, obtained from it by potassium hydroxide is identical with chitosan (B. **28**, 821, R. 476; C. 1908, II. 2016).

Elastin differs from albumin by its low sulphur content, and by its hydrolysis to glycocoll (25·75 per cent.) leucine (21·38 per cent.), alanine, phenyl alanine, valine, proline and glutaminic acid (C. 1904, I. 1364). **Keratin**, the main component of hair, nails, etc., possesses a very variable and sometimes particularly high sulphur content (0·7 to 5 per cent.) (B. **28**, R. 561); but in spite of this, its percentage composition is close to that of the proteïns. Keratin yields almost the same products as albumin, viz., leucine, tyrosine and serine (B. **35**, 2660). *Elastin* and *Keratin* are more difficultly soluble and decomposable than the true proteïn substances. Elastin is digested by pepsin and trypsin, but not keratin. Partial hydrolysis of elastin gives rise to several dipeptides—d-*alanyl l-leucine*, *glycyl valyl anhydride*, d-*alanyl prolyl anhydride* (B. **40**, 3544).

Fibroïn is the chief substance in silk which also contains *silk glue;* this is decomposed mainly into *serine* (p. 546). When left in solution in contact with cold concentrated hydrochloric acid it is converted into a peptone-like body, from which trypsin only produces *tyrosine*. The remaining peptone-like body is decomposed by acids or alkalis into *glycocoll* and d-*alanine*, or *glycyl* d-*alanine* (Ch. Ztg. 1902, 940). Also, a *tetrapeptide*, made up of glycocoll, alanine and tyrosine has been isolated by partial hydrolysis of silk-fibroïn (B. **40**, 3552).

Protamines, discovered by *Meischer* (Arbeiten, Leipzig, 1897) are obtained by treatment of fish-sperm with mineral acids. Hydrolytic decomposition and action of trypsin produce *lysine*, *arginine* and *histidine* (*Kossel*, Z. physiol. Ch. **25**, 165; B. **34**, 3233; C. 1905, I. 1721). The protamines are free from sulphur and phosphorus, and react with the biuret test, but do not give *Millon's* reaction.

Hæmoglobin occupies a position in physiology of the highest importance, and has been minutely studied chemically. In connection with this **chlorophyll** will be discussed, whilst the related gall-dyes will be found in the section *biliary substances*.

D. HÆMOGLOBINS

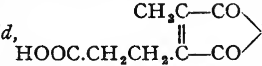
The *oxyhæmoglobins* are found in the arterial blood of animals and may be obtained in crystalline form by the addition of alcohol to an aqueous solution of blood corpuscles, after cholesterol and lecithin have been removed by shaking out with ether. The different oxyhæmoglobins, isolated from the blood of various animals, exhibit some variations, especially in crystalline form. Their elementary composition approximates very closely to that of albumin. It differs, however, by an iron content of 0·4 per cent. If the molecular weight of hæmoglobin be calculated in the supposition that it contains an atom of iron, the value obtained exceeds 13,000. The hæmoglobins are bright red, crystalline powders, very soluble in cold water, and are precipitated in crystalline form by alcohol. When the aqueous solution of oxyhæmoglobin is placed under reduced pressure or when it is exposed to the agency of reducing agents (ammonium sulphide) it parts with oxygen and becomes *hæmoglobin*. The latter is also present in venous blood, and may be separated out in a crystalline form (B. **19**, 128). Its aqueous solution absorbs oxygen very rapidly from the air, and reverts again to oxyhæmoglobin. Both bodies in aqueous solution exhibit characteristic absorption spectra, whereby they may be easily distinguished.

If carbon monoxide be conducted into the oxyhæmoglobin solution, oxygen is also displaced and hæmoglobin-carbon monoxide formed, which can be obtained in large crystals with a bluish colour. This explains the poisonous action of carbon monoxide.

The bluish-red solution of carbon monoxide in hæmoglobin, like oxyhæmoglobin, shows two characteristic absorption bands between the Fraunhofer lines D and E, which do not disappear on the addition of ammonium sulphide (method of differentiation from oxyhæmoglobin). Oxygen-free hæmoglobin shows one absorption band between D and E. =CO and O_2 enter into combination in equal volumes; it is, therefore, not a question of molecular attraction, but actual atomic union: $Hb{=}CO$ and $Hb\!<\!\begin{smallmatrix}O\\|\\O\end{smallmatrix}$. These compounds are partially dissociated above 0°. Equivalent quantities of other gases, such as NO_4, HNC, are absorbed by hæmoglobin. Hæmatochromogen (below) also absorbs one equivalent of CO.

At 70°, or by the action of acid or alkalis, oxyhæmoglobin is split up into a proteïn such as *globin* (hydrolysis, see *E. Fischer*, l.c. 695, 740), differing for each animal, fatty acids and the colouring matter *hæmatochromogen;* the latter substance, in contact with free oxygen passes into hæmatin. It contains 9 per cent. of iron, and corresponds with the formula $C_{34}H_{35}FeN_4O_5$ (*Hoppe-Seyler*), $C_{32}H_{32}N_4FeO_4$ (*Nencki* and *Sieber*) or $C_{32}H_{34}N_4FO_3$ (*Hüfner* and *Küster*).

If one drop of glacial acetic acid and very little sodium chloride be added to oxyhæmoglobin (or dried blood), microscopic reddish-brown crystals of *hæmin* or *hæmatin chloride*, $C_{34}H_{33}N_4O_4FeCl$ (?) are formed (B. **29**, 2877; **40**, 2021; A. **358**, 213), from which alkalis precipitate *hæmatin*, $C_{34}H_{33}N_4O_2FeOH$. The formation of these crystals serves as a delicate test for the detection of blood. The structural formula of hæmatin appears to be near its elucidation.

Oxidation with potassium bichromate breaks hæmatin down into the *imide* of the tribasic *hæmatic acid*,  $\begin{matrix}CH_3C{-}CO\\ \| \\ HOOC.CH_2CH_2.C{-}CO\end{matrix}\!\!>\!NH$, m.p. 114°, which yields the corresponding *anhydride acid*, $C_5H_7(CO_2H)(CO)_2O$, m.p. 97° when treated with alkalis. When heated above 120° it loses CO_2 and passes into the *imide* of the dibasic *methyl ethyl maleïc acid* (comp. p. 519).

When hæmatin is treated with hydrobromic acid it loses iron and is converted into *hæmatoporphyrin*, $C_{34}H_{38}N_4O_6$. Gentle action of hydriodic acid and phosphonium iodide produces *mesoporphyrin*, $C_{34}H_{38}N_4O_4$; more energetic treatment gives rise to an oxygen-free, volatile, easily altered oil, *hæmopyrrole*, $C_8H_{13}N$. It is probably an alkylated (methyl propyl?) pyrrole (Vol. II.), the more probably since the breaking-down of hæmatin (see above) by oxidation, gives rise to alkylated maleïc acid (B. **34**, 997; C. 1906, I. 1026).

CHLOROPHYLL

Under this heading are collected those vegetable colouring matters which occur in all the green portions of plants, and which play a rôle of the highest importance in physiological development in the vegetable, and therefore indirectly animal, kingdoms.

It is remarkable that chlorophyll, the green vegetable colouring matter, and hæmin, the colour in red blood, appear to be closely connected (p. 676). What iron is to hæmin, magnesium is to chlorophyll (*Willstätter*).

Amorphous chlorophyll is obtained by extracting the fresh or dried green parts of plants with alcohol, and the liquid thus formed is purified by shaking out with benzene or carbon disulphide and water. Purified chlorophyll is an amorphous green mass, still probably consisting of a mixture of substances, the ash of which consists of magnesia. Magnesium in the chlorophyll can be abstracted by dilute acids, and neutral ash-free substances result—chlorophyllan, phæophytin, phyllogen, etc. (comp. A. **354**, 207; B. **41**, 1352; C. 1908, II. 952). These seem to be partially of ester-like character, since hydrolysis with alcoholic potassium hydroxide liberates an alcohol *phytol*, $C_{20}H_{40}O$, b.p.$_{0\cdot 03}$ 145°, $D_0^{20} = 0\cdot 852$, whilst the acid portion consists of a mixture of substances, *phytochlorine* and *phytorhodin* (*Willstätter*).

Alkalis are not able to separate the magnesium even at 200°, but rather convert the chlorophyll into other substances containing magnesium, such as *rhodophyllin*, etc. (A. **358**, 205), from which dilute acids again produce ash-free bodies. A similar treatment converts chlorophyll into *phylloporphyrin*, which is closely similar to mesoporphyrin and hæmatoporphyrin (p. 675), as shown by its formula, $C_{34}H_{38}N_4O_8$ (?), its chemical reactions—it yields a pyrrole derivative, similar to hæmopyrrole—and its absorption spectrum (*Schunk* and *Marchlewski*, A. **290,** 306; B. **29,** 2877; **34,** 1687; **41,** 847).

The chemical relationship between hæmoglobin and chlorophyll indicates an analogous physiological activity; hæmoglobin takes up the oxygen from the air breathed into the lungs and gives it up to those organs of the body which require it, whilst chlorophyll abstracts oxygen from carbon dioxide and water and gives it up for the use of the animals.

Since the lower fungi which contain *no* chlorophyll are able to build up carbohydrates, fats, and proteïns from many different bodies containing the groups CH_2 and CHOH, there can be no doubt this synthesis is carried out by the living cell-substance to which the required atomic groups are delivered by reduction in the green parts of the plant (private information from *E. Pflüger*).

Crystallized chlorophyll, $C_{38}H_{42}O_7N_4Mg$ (?) and its reaction products, see A. **358,** 267; C. 1908, II. 715).

Carotin and *Xanthophyll* are red and yellow colouring matters which occur with chlorophyll in leaves, and give rise to the autumn colours.

Carotin, $C_{40}H_{56}$, m.p. 168°, is also obtained from carrots (*Daucus carota*); it forms red crystals.

Xanthophyll, $C_{40}H_{56}O_2$, m.p. 172°, forms yellow crystals. It is characterized by its beautiful iodine addition products; it absorbs oxygen energetically, and may be of significance in connection with the oxygen-breathing of plants as chlorophyll is for the CO_2 breathing (A. **355,** 1).

E. BILIARY SUBSTANCES

In the bile, the liquid secretion of the liver which assists in the emulsifying and absorption of fats, there exist a connected series of peculiar acids in the form of their sodium salts. The best known are *glycocholic acid* and *taurocholic acid;* also *lecithin* (p. 531), *cholesterol*, and some *bile pigments*.

Bilirubin, *Bilifuscin*, *Biliprasin*, $C_{32}H_{36}N_4O_6$ (?), is closely connected with the blood pigment. When oxidized with chromic acid it yields *biliverdic acid*, identical with *hæmatic acid* (p. 675) (B. **35,** 1268; C. 1905, I. 1253, 1906, I. 1498).

Cholalic Acid, *Cholic Acid*, m.p. anhydrous 195° (B. **27,** 1339; **28,** R. 233; **29,** R. 142), is obtained together with glycocoll when glycocholic acid is broken down, and with *taurin* when taurocholic is similarly acted on. It is a mono-basic acid. Glycocholic and taurocholic acids occur as sodium salts in bile. In the preparation of cholalic acid, *choleïnic acid*, $C_{24}H_{40}O_4$ and *fellic acid*, $C_{22}H_{38}O_4$, are also formed. Iodine produces a blue compound similar to that between iodine and starch (B. **28,** 785, R. 720). On the oxydation of cholic acid, see B. **32,** 683.

Glycocholic Acid, $C_{24}H_{39}O_4.NHCH_2CO_2H$, m.p. 153°, decomposes into cholalic acid and glycocoll (p. 385) when boiled with aqueous alkali hydroxides.

Taurocholic Acid, $C_{24}H_{39}O_4.NH.CH_2CH_2SO_3H$ (ταῦρος = ox, χολή = bile) is easily soluble in water and alcohol, and is decomposed when boiled with water into cholalic acid and taurine (p. 326).

Cholesterol, $C_{27}H_{45}OH$, m.p. 148°, b.p. about 360°, $[\alpha]_D = -31{\cdot}12°$ (in ether) occurs, partly free and partly as an ester with the higher fatty acids, in many parts of the animal organism, not only in the bile (χολή=bile, στέαρ=tallow), but also in gall-stones, which contain 90 per cent. cholesterol, in the brain, blood, egg-yolk, wool-fats, etc.

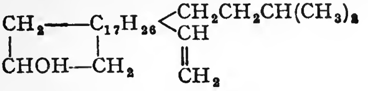
In the intestine cholesterol is reduced to *coprosterol*, $C_{27}H_{47}OH$ (?), m.p. 96°; a dextro-rotatory saturated alcohol (B. **29,** 476; C. 1908, II. 1279, 1500). Cholesterol protects the red blood corpuscles from hæmolysis by certain toxins; it acts, therefore, against invading poisons (C. 1905, I. 1265; B. **42,** 238).

Cholesterol is insoluble in water, but soluble in most organic solvents. It crystallizes from alcohol in mother-of-pearl leaflets or tables possessing a fatty feel, and containing one molecule of water; from ether it forms anhydrous needles. It is a secondary olefine alcohol, it takes up HCl, bromine (*dibromide*, $C_{27}H_{45}Br_2OH$, m.p. 125°, serves to characterize it), and hydrogen (*dihydrocholesterol*, $C_{27}H_{47}OH$, m.p. 142°, B. **41,** 2199).

Cholesteryl Chloride, $C_{27}H_{45}Cl$, m.p. 96°, is formed from cholesterol and thionyl chloride; sodium and amyl alcohol reduce it to cholestene, $C_{27}H_{46}$, m.p. 90° (B. **27**, R. 301). The esters of cholesterol were the first discovered substances found to possess a crystalline fluid condition (p. 46).

When heated to 310° cholesterol is partly converted into the (stereo- ?) isomeric *β-cholesterol*, m.p. 160°, which can also be formed by reduction of *cholestenone*, $C_{27}H_{44}O$, the ketone corresponding with cholesterol. It can be reconverted into the ordinary form of cholesterol through the benzoate (B. **41**, 160).

Cholesterol contains only one olefine bond, and, as is shown by its C : H ratio, a carbon ring; and is connected with the terpenes (Vol. II.). Its structure has been partially elucidated by an examination of its oxidation products (*Mauthner*, *Suida*, *Diels*, *Abderhalden*, *Windaus*; B. **41**, 2558, 2596). Without examining the matter in detail, it suffices to give the following provisional formula:—



$$\begin{array}{lll} \mathrm{CH_2}\!-\!\!-\!\!- & \mathrm{C_{17}H_{26}} & \!\!<\!\begin{array}{l}\mathrm{CH_2CH_2CH(CH_3)_2}\\ \mathrm{CH}\end{array} \\ | & | & \quad\ \ \| \\ \mathrm{CHOH}\!-\!\!- & \mathrm{CH_2} & \quad\ \ \mathrm{CH_2}\end{array}$$

According to this, chlolesterol is a polycyclic, secondary ring alcohol, with several side chains, among which an isoamyl and a vinyl group are to be identified, the latter giving easy opportunity for further ring formation, similarly to what happens among the olefinic terpenes (Vol. II.).

Cholic acid (p. 676) should be related to cholesterol, but still more closely allied appears to be *chenocholic acid*, $C_{27}H_{44}O_4$, which occurs in the bile of geese (A. **149**, 185).

The esters of cholesterol and *isocholesterol*, m.p. 138°, with the higher fatty acids are the constituents of *lanolin* or *wool fat* which is found on uncleaned sheep's wool, and is employed as an ointment, since it has the peculiarity ot being absorbed by the skin.

In the mixture of soaps, resulting on saponification of lanolin, there have been isolated *lanoceric acid*, $C_{30}H_{60}O_4$, m.p. 104°, *lanopalmitic acid*, $C_{16}H_{32}O_3$, m.p. 87°, myristic acid (p. 262) and *carnaubic acid*, $C_{24}H_{48}O_2$ (B. **29**, 2890).

Cholesterol-like substances have been found in plants. *Phytosterol*, isomeric with cholesterol, occurs in seeds and plant-germs (B. **24**, 187). α- and *β-Amyrin*, from *Elemi resin* (B. **24**, 3836), and *lupeol* (B. **24**, 2709) from the seed husks of *Lupinus luteus* are other examples. *Hippocoprosterol*, or *chortosterol*, $C_{27}H_{53}OH$, m.p. 79° (C. 1908, II. 1277).

F. UNORGANIZED FERMENTS OR ENZYMES

(Comp. p. 113.)

The unorganized ferments, which play an important rôle in fermentation, many putrescing processes, and digestion, are produced from animal and vegetable cells. They are of unknown structure, soluble in water, and lose their activity on being boiled. Their influence is mainly hydrolytic. It is striking that for the hydrolytic decomposition of different substances, almost always different enzymes are required. Pepsin and trypsin hydrolyze proteïns but not fats or starch; the diastatic ferment of saliva hydrolyzes starch, but has no action on fats. The configuration of glucosides has a definite influence on the action of enzymes (B. **28**, 984, 1429). Vegetable enzymes are: *invertin*, *diastase* (p. 113), *emulsin* or *synaptase* in bitter almonds, *papayotin*, from the fruit of the paupaw (*Carica papaya*), all producing far-reaching decomposition of proteïns (B. **35**, 695).

Nomenclature of enzymes (B. **36**, 331).

On the inclusion of *zymase*, the active fermentative principle in the juice expressed from yeast, as an enzyme (see p. 112).

INDEX

SUBSTANCES should also be sought in the more general paragraphs of the various sections and derivatives, also under the various compounds.

END OF VOL. I.

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