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PROBLEMS AND EXERCISES IN CHEMISTRY

MIR PUBLISHERS · MOSCOW

ИЗДАТЕЛЬСТВО * МИР *

С. И. ВАСЮЧЕНКО

СБОРНИК ЗАДАЧ И УПРАЖНЕНИЙ ПО ХИМИИ

ИЗДАТЕЛЬСТВО «ВЫСШАЯ ШКОЛА»
МОСКВА

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PROBLEMS AND EXERCISES IN CHEMISTRY

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FOREWORD

This is the translation of the third revised and enlarged Russian edition of the textbook, which is intended for the secondary and vocational schools, and is a companion volume to the sixth edition of Vasyuchenko's *Chemistry* (1966).

The problems in each section are preceded by concise reviews of theoretical principles and exemplary solutions of typical problems. The numeration of the problems consists of two parts, the first designating the chapter to which a particular problem belongs and the second figure denoting the ordinal number of the problem within the given chapter. For example, problem 5 in Chapter Six is designated 6.5.

CONTENTS

INTRODUCTION

Solving chemical problems is as important as the study of the theory, demonstrations, and laboratory exercises and experiments.

This collection mostly contains problems involving various calculations from chemical formulas and equations. The accuracy of calculation should in most cases be to 0.01, though 0.1 will also be sufficient, and in certain problems the results can be rounded to whole numbers.

The table appended to the textbook gives rounded atomic weights of some most important chemical elements that should be used in solving problems.

The author does not think it necessary to recommend to convert in all cases the units of mass and volume given in the condition of the problem into gram-atoms, gram-molecules, etc., since very often it may only add difficulties and make the computation more complicated, though in some cases it will markedly simplify calculations from chemical formulas and equations. For this reason the student should decide by himself which unit will suit the particular purpose better.

Practical problems in the chapters or sections are preceded by brief theoretical introductions and appropriate instructions.

CHAPTER ONE

BASIC CONCEPTS AND LAWS OF CHEMISTRY. THEORY OF ATOMS AND MOLECULES

1. Gram-Atom. Gram-Molecule

A unit accepted in chemistry to express the mass of the atom and molecule is the carbon unit, which is 1/12 the mass of carbon 12.

Atomic mass is the number expressing the mass of one atom of an element in carbon units.

Gram-atom (*g-atom*, for short) is the number of grams of an element equal numerically to the atomic mass of a given element. For example, the mass of one gram-atom of H is 1 g, of O, 16 g, Na, 23 g, Fe, 56 g, etc.

Molecular mass is the number expressing the mass of one molecule of a substance in carbon units. For example, the molecular mass of one molecule of H_2O is 18 carbon units, of FeS, 88, etc.

Gram-molecule (*mole*, for short) is a quantity of a substance, the mass of which in grams is numerically equal to the mass of the substance. For example, the mass of one gram-molecule of H_2O is 18 g, one mole of FeS, 88 g, etc.

PROBLEMS

1.1. What is the mass in grams of (a) three g-atoms of carbon? (b) one g-atom of oxygen? (c) 10 g-atoms of magnesium? (d) 0.25 g-atom of sulphur?

1.2. Express in gram-atoms (a) 4 g of oxygen; (b) 20 g of hydrogen; (c) 12 g of magnesium; (d) 112 g of iron; (e) 40 g of helium; (f) 7 g of silicon.

1.3. Express in gram-atoms (a) 40 g of neon; (b) 6 g of carbon; (c) 46 g of sodium; (d) 21 g of nitrogen; and (e) 54 g of aluminium.

1.4. Express in gram-molecules (a) 234 g of sodium chloride NaCl; (b) 360 g of water; (c) 4.4 g of carbon dioxide CO_2.

1.5. Express in gram-molecules (a) 54.25 g of mercury oxide HgO; (b) 4 g of sulphur dioxide SO_2; (c) 176 g of ferrous sulphide FeS.

1.6. Determine the mass of one kilogram-molecule of (a) water H_2O; (b) potassium hydroxide KOH; (c) soda Na_2CO_3; (d) hydrochloric acid HCl.

1.7. Express in kilogram-molecules (a) 360 kg of ferrous disulphide FeS_2; (b) 1,600 kg of ferric oxide Fe_2O_3; (c) 234 kg of common salt $NaCl$; (d) 906 kg of stannic oxide SnO_2.

1.8. Express in milligram-molecules (a) 0.04 g of sodium hydroxide $NaOH$; (b) 0.063 g of nitric acid HNO_3; (c) 0.01 g of calcium carbonate $CaCO_3$.

1.9. How many gram-molecules are contained in one litre of water?

1.10. How much is one substance heavier than the other in the following pairs: (a) water vapour H_2O and nitric oxide NO; (b) calcium carbonate $CaCO_3$ and mercury oxide HgO; (c) sodium hydroxide $NaOH$ and potassium hydroxide KOH?

2. Gram-Molecular Volume. Relative Density of Gas

The solution of many problems dealing with gases is simplified if the Law of Avogadro is applied.

According to the Law of Avogadro, equal volumes of gases (or vapours) at the same pressure and the same temperature contain equal numbers of molecules.

The volume of a gram-molecule of a gas or vapour (molecular volume) in normal conditions* is 22.4 litres (rounded).

The relative density of a gas with respect to hydrogen or air can be easily calculated if the chemical formula of the gas is known.

The molecular weight (M) of a gas (or vapour) is equal to its doubled density with respect to hydrogen (D_H):

$$M = 2D_H$$

whence

$$D_H = \frac{M}{2}$$

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* At 760 Hg and 20°C.

The mean molecular weight of air is 29 (rounded). Hence, the density of a gas with respect to air (D_{air}) is

$$D_{air} = \frac{M}{29}$$

Since a gram-molecule of a gas at NTP occupies a volume of 22.4 litres, it follows that, knowing the chemical formula of a particular gas, one can calculate: (a) the volume V occupied by one gram of this gas at NTP:

$$V = \frac{22.4}{M}$$

(b) the mass m of one litre of the gas at NTP:

$$m = \frac{M}{22.4}$$

And vice versa, if the mass of one litre of a gas at NTP is known, one can easily calculate the gram-molecular weight (mole) of the gas by using the formula

$$1 \text{ mole} = 22.4 \text{ litres}$$

Determination of density of a gas with respect to hydrogen D_H from the molecular weight of the gas.

Example 1. What is the density of carbon dioxide CO_2 with respect to hydrogen?

Solution: The molecular weight of CO_2 is 44 ($12 + 16 \times \times 2 = 44$) whence

$$D_H = \frac{44}{2} = 22$$

Answer: Carbon dioxide is 22 times heavier than hydrogen.

Determination of density of a gas with respect to air D_{air} from the molecular weight of the gas.

Example 2. Calculate the density of carbon dioxide CO_2 with respect to air.

Solution: The molecular weight of CO_2 is 44.

$$D_{air} = \frac{M}{29}; \quad D_{air} = \frac{44}{29} \approx 1.5$$

Answer: Carbon dioxide is about 1.5 times heavier than air.

Determination of density of a gas with respect to air if the density of the gas with respect to hydrogen is known.

Example 3. The density of sulphur dioxide with respect to hydrogen (D_H) is 32. What is the density of this gas with respect to air?

Solution: The molecular weight of sulphur dioxide is

$$M = 2 \times 32 = 64$$

whence the density of sulphur dioxide with respect to air is

$$D_{air} = \frac{64}{29} = 2.2$$

Determination of mass of a given volume of a gas at NTP.

Example 4. Determine the mass of one litre of oxygen at NTP.

Solution: In order to calculate the mass of one litre of any gas or vapour at NTP, the molecular weight of the gas should be divided by 22.4.

The formula of oxygen is O_2, its molecular weight is 32 (16 × 2); the mass of one mole is 32 g. The 32 g of oxygen at NTP occupy a volume of 22.4 litres, hence

$$x = \frac{32}{22.4} \approx 1.43 \text{ g/litre}$$

Answer: The mass of one litre of oxygen measured in normal conditions is about 1.43 g.

Determination of volume of the required quantity of a gas at NTP.

Example 5. What is the volume of 1 g of carbon dioxide at NTP?

Solution: In order to calculate the volume occupied by one gram of the gas at NTP, 22.4 should be divided by the molecular weight of the gas.

The molecular weight of CO_2 is 44, the mass of one mole of CO_2 is 44 g.

At NTP, 44 g of CO_2 occupy a volume of 22.4 litres, whence

$$x = \frac{22.4}{44} \approx 0.51 \text{ litre/g}$$

Answer: One gram of CO_2 at NTP occupies a volume of 0.51 litre.

Determination of weight of a given volume of a gas at NTP from the molecular weight of the gas.

Example 6. The molecular weight of a gas is 64. The mass of one mole of the gas is 64. What is the mass of one litre of this gas at NTP?

Solution:

$$m = \frac{64}{22.4} = 2.86 \text{ g/litre}$$

Answer: The mass of one litre of a given gas measured in normal conditions is 2.86 g.

Determination of the molecular weight of a gas from the mass of a given volume of the gas.

Example 7. The mass of one litre of hydrogen measured in normal conditions is 0.089 g (rounded). What is the molecular weight of hydrogen?

Solution: The mass of one mole of hydrogen is

$$22.4 \times 0.089 = 2 \text{ g}$$

whence

$$M = 2 \text{ (carbon units)}$$

Answer: The molecular weight of hydrogen is 2.

PROBLEMS

1.11. What is the density with respect to hydrogen of (a) nitrogen and carbon dioxide CO_2; (b) methane CH_4 and nitrogen dioxide; (c) nitric oxide NO and sulphur dioxide SO_2?

1.12. What is the density with respect to hydrogen of (a) hydrogen sulphide H_2S and ammonia NH_3; (b) hydrogen phosphide PH_3 and chlorine Cl_2?

1.13. What is the density with respect to air of (a) carbon dioxide CO_2 and oxygen O_2; (b) nitrogen dioxide NO_2 and sulphur dioxide SO_2; (c) chlorine Cl_2 and ammonia NH_3?

1.14. What is the density with respect to air of (a) nitrous oxide N_2O and methane CH_4; (b) carbon monoxide CO and hydrogen sulphide H_2S?

1.15. What is the density with respect to air of propane, if its density with respect to hydrogen is 22?

1.16. What is the mass at NTP of (a) one litre of CO_2 and 10 litres of CO; (b) 4 litres of NO_2 and 10 litres of NH_3; (c) 22 litres of CH_4 and 5 litres of NO?

1.17. Calculate the volume occupied at NTP by (a) 4 g of oxygen O_2 and 10 g of nitrogen N_2; (b) 2.5 g f CO_2 and 30 g of H_2; (c) 10 g of O_2 and 50 g of H_2.

1.18. What is the weight of one litre of a gas at NTP if its molecular weight is (a) 46; (b) 34; (c) 71?

1.19. What is the molecular weight of a gas if the mass of its one litre at NTP is (a) 1.96 (rounded); (b) 2.9 (rounded)?

3. Calculations from Chemical Formulas

A chemical formula is a symbolic expression of the composition of a substance. Various problems can be solved by using chemical formulas of substances.

Calculation of quantitative ratios of the elements in a chemical compound. If the formula of a chemical substance is known, one can determine the quantitative ratio of the elements in this compound. Since a substance consists of identical molecules, it is sufficient to calculate the quantitative ratio of the elements in one molecule.

Example 1. What is the ratio of iron (Fe) to oxygen (O) in (a) ferrous oxide FeO, and (b) ferric oxide Fe_2O_3?

Solution:

$$\underset{56:16}{FeO} \quad \text{whence } 56:16=7:2$$

$$\underset{112:48}{Fe_2O_3} \quad \text{whence } 112:48=7:3$$

Calculation of the percentage content of an element in a chemical compound. The percentage content of each element in a chemical compound can be calculated from the chemical formula.

The percentage content of an element in a substance is the ratio of the quantity of a given element contained in a molecule of a substance to the mass of the whole molecule, expressed in per cent.

Example 2. Calculate the percentage content of copper in cupric oxide CuO.

Solution: The molecular weight of cupric oxide is 64 + + 16 = 80.

A mole of CuO, the mass of which is 80 g, contains 64 g of Cu, which is $\frac{64}{80}$ of the mass of one mole.

To express this fraction in per cent, it should be multiplied by 100:

$$x_{\text{Cu}} = \frac{64}{80} \times 100 = 80 \text{ per cent}$$

Hence, copper oxide CuO contains 80 per cent of copper.

Calculation of percentage composition of a substance from its chemical formula. Calculation of the percentage composition of a complex substance means the determination of the percentage content of each element in it.

Example 3. Calculate the percentage composition of sodium hydroxide NaOH.

Solution: The molecular weight of NaOH is 23 + 16 + + 1 = 40. The percentage content of sodium is

$$\frac{23}{40} \times 100 = 57.5 \text{ (per cent)}$$

of oxygen

$$\frac{16}{40} \times 100 = 40 \text{ (per cent)}$$

of hydrogen

$$\frac{1}{40} \times 100 = 2.5 \text{ (per cent)}$$

Answer: Sodium hydroxide contains 57.5 per cent of sodium, 40 per cent of oxygen and 2.5 per cent of hydrogen.

Calculation of quantity of a substance containing the known quantity of an element.

Example 4. Calculate the quantity of carbon dioxide CO_2 that contains 3 g of carbon.

Solution: The molecular weight of CO_2 is 12 + (16 × 2) = = 44.

One mole of CO_2 weighs 44 g

By using the proportion method:

$$44 : x = 12 : 3$$

whence

$$x=\frac{44\times 3}{12}=11$$

Answer: 3 g of carbon are contained in 11 g of carbon dioxide.

Calculation of quantity of an element, given the quantity of a substance.

Example 5. How many grams of oxygen are contained in 16 g of sulphur dioxide SO_2?

Solution: The molecular weight of SO_2 is $32 + (16 \times \times 2) = 64$.

One mole of SO_2 weighs 64 g

The formula SO_2 shows that one mole of sulphur dioxide (i.e. 64 g) contains 2 g-atoms of oxygen, i.e. 32 g of oxygen.

By using the proportion method:

$$64 : 16 = 32 : x$$

Solving for x:

$$\frac{16\times 32}{64}=8$$

Answer: 16 g of sulphur dioxide contain 8 g of oxygen.

Complicated versions of problems of the above types. As a rule, substances used in the laboratory are not pure, and the calculations in chemical problems consist therefore in determining amounts of elements contained in mixtures of substances, or in determining total amounts of mixtures from the known quantity of an element in a substance, etc.

Example 6. A sample of red iron ore (red hematite), which is a natural iron oxide, contains 92 per cent of ferric oxide Fe_2O_3, the rest being admixtures containing no iron.

Determine the iron content of one ton of this ore.

Solution: (1) What quantity of ferric oxide Fe_2O_3 is contained in one ton of the ore?

$$100 : 1 = 92 : x$$

$$x=\frac{1\times 92}{100}=0.92 \text{ ton}$$

(2) What quantity of iron is contained in one ton of the ore?

$$\begin{array}{cc} Fe_2O_3-2Fe \\ 160 \quad 112 \end{array}$$

$$160:0.92=112:x$$

$$x=\frac{0.92\times 112}{160}=0.644$$

Answer: One ton of the ore contains 0.644 ton of iron.

Example 7. What quantity of copper is contained in 200 g of a 5 per cent solution of copper sulphate $CuSO_4$?

Solution: (1) 100 g of the solution contain 5 g of $CuSO_4$
200 g of the solution contain x g of $CuSO_4$

$$x=\frac{200\times 5}{100}=10 \text{ g}$$

(2) What quantity of copper is contained in 10 g of $CuSO_4$?

$$\begin{array}{ccc} CuSO_4-Cu & & 160-64 \\ 160 \quad 64 & & 10-x \end{array}$$

$$x=\frac{64\times 10}{160}=4$$

Answer: 200 g of a 5 per cent solution of copper sulphate contain 4 g of copper.

Example 8. What quantity of a 15 per cent solution of sodium chloride contains 2 g of chlorine?

Solution: (1) What quantity in grams of NaCl contains 2 g of chlorine?

$$\begin{array}{ccc} NaCl-Cl & & 58.5-35.5 \\ 58.5 \quad 35.5 & & x-2 \end{array}$$

$$58.5:x=35.5:2$$

$$x=\frac{58.5\times 2}{35.5}=3.29$$

(2) 100 g of the solution contain 15 g of NaCl
x g of the solution contain 3.29 g of NaCl

$$100:x=15:3.29$$

$$x=\frac{100\times 3.29}{15}$$

$$x=21.9$$

Answer: 21.9 g.

PROBLEMS

1.20. What are the weight ratios of (a) magnesium and oxygen in magnesium oxide MgO; (b) copper and oxygen in cupric oxide CuO; (c) silver and sulphur in silver sulphide Ag_2S; (d) sodium, oxygen and hydrogen in sodium hydroxide $NaOH$?

1.21. Calculate the percentage content of (a) hydrogen in slaked lime $Ca(OH)_2$, hydrochloric acid HCl, and methane CH_4; (b) oxygen in cupric oxide CuO, mercury oxide HgO, ferric oxide Fe_2O_3; (c) nitrogen in nitric acid HNO_3, ammonia NH_3, ammonium chloride NH_4Cl; (d) sulphur in ferrous sulphide FeS, sulphur dioxide SO_2, sulphuric acid H_2SO_4.

1.22. Which of the substances given below contains the greatest quantity of sodium: (a) sodium chloride $NaCl$; (b) saltpetre $NaNO_3$; (c) soda Na_2CO_3; (d) sodium sulphate Na_2SO_4?

1.23. Which ore is the richest in iron: red hematite Fe_2O_3, magnetite Fe_3O_4, limonite $2Fe_2O_3 \cdot 3H_2O$, or siderite $FeCO_3$? Assume that each ore contains 10 per cent of nonferrous admixtures.

1.24. Commercial aluminium chloride contains 98 per cent of $AlCl_3$, the rest being admixtures. Calculate the percentage content of chlorine in this chemical product.

1.25. Impure magnesium sulphate contains 96 per cent of $MgSO_4$ (4 per cent—admixtures containing no magnesium). What quantity in per cent of magnesium does this chemical product contain?

1.26. Calculate the percentage composition of the following substances: (a) potassium hydroxide KOH; (b) carbonic acid H_2CO_3; (c) sulphurous acid H_2SO_3; (d) chromium chloride $CrCl_2$; (e) calcium sulphate $CaSO_4$; (f) magnesium nitrate $Mg(NO_3)_2$; (g) ferric sulphate $Fe_2(SO_4)_3$; (h) calcium phosphate $Ca_3(PO_4)_2$; (i) soda Na_2CO_3; (j) limestone $CaCO_3$.

1.27. What quantity in grams of sulphur dioxide SO_2 contains (a) 4 g-atoms of sulphur; (b) 8 g-atoms of oxygen?

1.28. What quantity in grams of copper oxide CuO contains (a) 2 g-atoms of copper; (b) 3.2 g-atoms of oxygen?

1.29. What quantity in kilograms of limestone $CaCO_3$ contains (a) 1.4 kg-atoms of calcium; (b) 3 kg-atoms of carbon; (c) 0.3 kg-atom of oxygen?

1.30. How many moles of potassium chlorate $KClO_3$ contain (a) 195 g of potassium; (b) 213 g of chlorine; (c) 96 g of oxygen?

1.31. What quantity in gram-molecules of aluminium sulphate $Al_2(SO_4)_3$ contains (a) 162 g of aluminium; (b) 288 g of sulphur; (c) 19.2 g of oxygen?

1.32. How many moles of sodium phosphate contain (a) 138 g of sodium; (b) 6.2 g of phosphorus; (c) 640 g of oxygen?

1.33. A certain quantity of copper ore contains 8 kg-atoms of copper. What quantity of copper oxide CuO does this ore sample contain?

1.34. Iron ore which is a natural oxide of iron Fe_2O_3, is known as red iron ore or red hematite. A sample of red iron ore weighing 80 g contains 3 g-atoms of iron. Calculate the percentage content of admixtures in the given sample of ore.

1.35. What quantities in kilograms of (a) calcium cyanamide $CaCN_2$; (b) potassium nitrate KNO_3; (c) ammonium nitrate NH_4NO_3; (d) sodium nitrate $NaNO_3$ should be introduced into soil to give it the required 2.5 kg-atoms of nitrogen? Assume the substances to be free of admixtures.

1.36. How many kilograms of (a) sylvine KCl; (b) sylvinite $NaCl \cdot KCl$; (c) potash K_2CO_3; (d) wood ashes containing 40 per cent of potash K_2CO_3 should be introduced into soil to give it 2 kg-atoms of potassium?

1.37. How many gram-atoms of oxygen are contained in 232 g of (a) silver oxide Ag_2O; (b) magnesia MgO; (c) calcium oxide CaO?

1.38. How many grams of nitrogen are contained in 0.5 mole of (a) ammonia NH_3; (b) nitrous oxide N_2O; (c) nitric oxide NO; (d) nitrous anhydride N_2O_3; (e) nitrogen dioxide NO_2; (f) nitric anhydride N_2O_5? (Do mental arithmetic.)

1.39. How many kilogram-atoms of carbon are contained in one ton of (a) marble $CaCO_3$; (b) magnesite $MgCO_3$; (c) siderite $FeCO_3$?

1.40. How many gram-atoms of sulphur are contained in 10 moles of (a) hydrogen sulphide H_2S; (b) sulphur dioxide SO_2; (c) sulphur trioxide SO_3; (d) sulphurous acid H_2SO_3; (e) sulphuric acid H_2SO_4; (f) sodium sulphate Na_2SO_4?

1.41. What quantity of carbon is contained in (a) one mole of carbon dioxide CO_2; (b) 4 moles of carbon disulphide CS_2; (c) 0.1 mole of potash K_2CO_3; (d) 1.5 moles of soda Na_2CO_3?

1.42. What quantity of gram-atoms of zinc are contained in (a) 810 g of zinc oxide ZnO; (b) 194 g of zinc sulphide ZnS; (c) 250 g of zinc carbonate $ZnCO_3$; (d) 68 g of zinc chloride $ZnCl_2$?

1.43. From the formula SO_2 determine (a) the ratio of sulphur to oxygen in sulphur dioxide; (b) percentage composition of the substance; (c) quantity in grams of sulphur contained in 0.25 mole of SO_2; (d) quantity in grams of oxygen contained in 1.25 moles of SO_2; (e) quantity of SO_2 containing 3.2 g-atoms of sulphur.

1.44. What quantity of phosphorus is contained in (a) 1 kg of bone meal containing 88 per cent of $Ca_3(PO_4)_2$; (b) 2 tons of phosphorite meal containing 82 per cent of $Ca_3(PO_4)_2$; (c) 0.5 ton of double superphosphate containing 92 per cent of $Ca(H_2PO_4)_2$?

Express the answer in per cent of P_2O_5 and in kilogram-atoms of phosphorus.

1.45. What quantity in grams of iron is contained in 100 g of a 25 per cent solution of ferrous sulphate $FeSO_4$?

1.46. What quantity of a 20 per cent solution of ferrous sulphate $FeSO_4$ contains 4 g of iron?

4. Calculations from Chemical Equations

The chemical equation is the expression of a chemical reaction with chemical formulas.

Quantities of substances corresponding to the chemical equation are called *stoichiometric quantities*, and the calculations from chemical equations are known as *stoichiometric calculations*.

Consider four typical cases of calculations from chemical equations, using the reaction of copper displacement from its sulphate $CuSO_4$ by iron as an example:

$$CuSO_4 + Fe = FeSO_4 + Cu$$

Determination of quantity of one of the reaction products, given the quantity of one of the starting substances.

Example 1. How many grams of copper can be obtained from 16 g of copper sulphate by acting on it with the necessary quantity of iron?

Solution:

$$\underset{160\ g}{\overset{16\ g}{CuSO_4}} + Fe = FeSO_4 + \underset{64\ g}{\overset{x\ g}{Cu}}$$

$$160 : 16 = 64 : x$$

$$x = \frac{16 \times 64}{160} = 6.4$$

Answer: 6.4 g.

Determination of quantity of one of the starting substances, given the quantity of one of the reaction products.

Example 2. How many grams of copper sulphate will liberate 8 g of copper by reacting with the necessary quantity of iron?

Solution:

$$\underset{160\ g}{\overset{x\ g}{CuSO_4}} + Fe = FeSO_4 + \underset{64\ g}{\overset{8\ g}{Cu}}$$

$$160 : x = 64 : 8 \quad x = \frac{160 \times 8}{64} = 20$$

Answer: 20 g.

Determination of quantity of a starting substance, given the quantity of the other reactant.

Example 3. How many grams of iron will displace all copper from 80 g of copper sulphate?

Solution:

$$\underset{160\ g}{\overset{80\ g}{CuSO_4}} + \underset{55\ g}{\overset{x\ g}{Fe}} = FeSO_4 + Cu$$

$$160\ g - 56\ g \quad 160 : 80 = 56 : x$$

$$80\ g - x\ g \quad x = \frac{80 \times 56}{160} = 28$$

Answer: 28 g.

Determination of quantity of a reaction product, given the quantity of the other product of the reaction.

Example 4. How many grams of ferrous sulphate will be formed in solution, if 128 g of copper are liberated in the reaction between a solution of copper sulphate and the required quantity of iron?

Solution:

$$CuSO_4 + Fe = \underset{152\text{ g}}{\overset{x\text{ g}}{FeSO_4}} + \underset{64\text{ g}}{\overset{128\text{ g}}{Cu}}$$

$$152\text{ g} - 64\text{ g} \qquad 152 : x = 64 : 128$$

$$x\text{ g} - 128\text{ g} \qquad x = \frac{152 \times 128}{64} = 304$$

Answer: 304 g.

Consider more complicated versions of problems of the above four types.

Determination of quantity of a reaction product, given the quantity of a starting reactant containing the known percentage of admixtures or taken in the form of a solution of the known concentration.

Example 5. How many kilograms of CO_2 can be obtained by calcining 10 kg of magnesite containing 94 per cent of magnesium carbonate $MgCO_3$?

Solution: (1) How much $MgCO_3$ is contained in 10 kg of the said sample of magnesite?

$$100\text{ kg} - 94\text{ kg} \qquad 100 : 10 = 94 : x$$

$$10\text{ kg} - x\text{ kg} \qquad x = \frac{10 \times 94}{100} = 9.4$$

(2) How much CO_2 is formed in calcining 9.4 kg of $MgCO_3$?

$$\underset{84}{\overset{9.4\text{ kg}}{MgCO_3}} = Mg + \underset{44}{\overset{x\text{ kg}}{CO_2}}$$

$$84 - 44 \qquad 84 : 9.4 = 44 : x$$

$$9.4 - x \qquad x = \frac{9.4 \times 44}{84} = 4.92$$

Answer: 4.92 kg.

Determination of the yield of a reaction product in per cent of theory.

Example 6. The yield of oxygen in electrolysis of 40 moles of water is 620 g. Determine the yield of oxygen in per cent of theory.

Solution: (1) What quantity in grams of oxygen will be liberated in electrolysis of 40 moles of water at 100 per cent yield?

$$\underset{2\ \text{moles}}{\overset{40\ \text{moles}}{2H_2O}} = 2H_2 + \underset{32\ g}{\overset{x\ g}{O_2}}$$

$$2\ \text{moles} - 32\ g \qquad 2:40 = 32:x$$

$$40\ \text{moles} - x\ g \qquad x = \frac{40 \times 32}{2} = 640\ g$$

(2) What is the yield of oxygen in per cent of theory?

$$640\ g - 100\ \text{per cent yield}$$

$$620\ g - x$$

$$x = \frac{620 \times 100}{640} = 96.88$$

Answer: 96.88 per cent.

Determination of quantity of a reaction product, given the quantity of a starting substance, provided its yield in per cent of theory is known.

Example 7. How much hydrogen can be prepared from 49 g of sulphuric acid by reacting it with the required quantity of zinc, if the yield of hydrogen is 94 per cent of theory?

Solution: (1) How much H_2 is liberated in the interaction between 49 g of H_2SO_4 and the required quantity of Zn, if the yield is 100 per cent?

$$\underset{98\ g}{\overset{49\ g}{H_2SO_4}} + Zn = ZnSO_4 + \underset{2\ g}{\overset{x\ g}{H_2}}$$

$$98\ g - 2\ g \qquad 98:49 = 2:x$$

$$49\ g - x\ g \qquad x = \frac{49 - 2}{98} = 1\ g$$

(2) How much hydrogen will be liberated if the yield is 94 per cent of theory?

$$1\ \text{g} - 100\ \text{per cent} \qquad 1 : x = 100 : 94$$

$$x\ \text{g} - 94\ \text{per cent} \qquad x = \frac{1 \times 94}{100} = 0.94$$

Answer: 0.94 g.

Determination of quantity of a reaction product, given the quantities of two starting substances, one of which is taken in excess. In solving these problems, the substance which is taken in excess is determined first. To this end, the quantity of one starting substance is designated by *y*, and its value is determined from the known quantity of the other starting substance; the resultant value of *y* is compared against the given quantity of this substance. The yield of the reaction product is calculated with reference to the starting substance which is deficient.

Example 8. How much sodium nitrate can be obtained by acting with 130 g of nitric acid on a solution containing 80 g of sodium hydroxide? (The starting substances should be assumed as containing no admixtures, the yield of the salt being 100 per cent of theory.)

Solution: (1) What quantity in grams of HNO_3 is required to neutralize completely 80 g of NaOH?

$$\underset{40\ \text{g}}{\overset{80\ \text{g}}{NaOH}} + \underset{63\ \text{g}}{\overset{130\ \text{g}\ (y)}{HNO_3}} = \underset{85\ \text{g}}{\overset{x\ \text{g}}{NaNO_3}} + H_2O$$

$$40\ \text{g} - 63\ \text{g} \qquad 40 : 80 = 63 : y$$

$$80\ \text{g} - y\ \text{g} \qquad y = 126\ \text{g}$$

Hence, 4 g of HNO_3 (130 − 126 = 4) remain in excess.

(2) How many grams of $NaNO_3$ can be formed from 80 g of NaOH?

$$40 - 85 \qquad 40 : 80 = 85 : x$$

$$80 - x \qquad x = \frac{85 \times 80}{40} = 170$$

Answer: 170 g of sodium nitrate are prepared by the reaction between 130 g of nitric acid and a solution containing 80 g of NaOH; 4 g of the acid remain unreacted.

Calculations from chemical equations by using gram-molecular volume of gas at normal conditions.

Example 9. What quantity in litres of hydrogen can be obtained in electrolysis of 6 g of water?

Solution:

$$\begin{array}{ll} \text{6 g} & x\ \text{l} \\ 2H_2O & =2H_2+O_2 \\ \text{2 moles} & \text{2 moles} \\ \text{36 g} & 22.4\times 2\ \text{litres} \end{array}$$

$$\begin{array}{ll} \text{36 g of } H_2O \text{ give} & 44.8 \text{ litres of } H_2 \\ \text{6 g of } H_2O \text{ give} & x \text{ litres of } H_2 \end{array}$$

By using the proportion method:

$$36 : 6 = 44.8 : x$$

and solving for x we have:

$$x=\frac{6\times 44.8}{36}=\frac{44.8}{6}\approx 7.47 \text{ litres}$$

Answer: About 7.47 litres of hydrogen are liberated in electrolysis of 6 g of water.

Solution of problems from stoichiometric schemes. While solving problems from chemical equations, one would usually begin with writing down the reaction equation. Next stoichiometric quantities of substances taking part in the reaction are calculated and written down, and proportion is made for determining the unknown.

Example 1. What quantity in grams of magnesium oxide is formed on complete burning of 12 g of magnesium?

Solution:

$$\begin{array}{lcl} 2Mg+O_2 & = & 2MgO \\ 2\times 24 & & 2\times 40 \end{array}$$

$$\begin{array}{l} \text{48 g of Mg produce 80 g of MgO} \\ \text{12 g of Mg produce } x \text{ g of MgO} \end{array}$$

By using the proportion:

$$48 : 12 = 80 : x$$

whence

$$x=\frac{12\times 80}{48}=20$$

Answer: 12 g of magnesium produce 20 g of magnesia on burning.

The condition of the problem does not specify the quantity of oxygen consumed in burning the 12 g of magnesium. The scheme of the reaction is either $2Mg \rightarrow 2MgO$ or $Mg \rightarrow MgO$. But the calculation of the quantity of magnesia produced by either of these schemes gives the same result:

$$\begin{array}{ll}
Mg \quad MgO & 2Mg \quad 2MgO \\
24\,g - 40\,g & 48\,g - 80\,g \\
12\,g - x\,g & 12\,g - x\,g \\
24 : 12 = 40 : x & 48 : 12 = 80 : x \\
x = \frac{12 \times 40}{24} = 20 & x = \frac{12 \times 80}{48} = 20
\end{array}$$

Example 2. What quantity of phosphorus is required to prepare 20 g of metaphosphoric acid HPO_3?

Solution: Phosphorus pentoxide is formed by burning phosphorus:

$$4P + 5O_2 = 2P_2O_5$$

It reacts with water to produce metaphosphoric acid:

$$\begin{array}{ccc}
x\,g & & 20\,g \\
P_2O_5 + H_2O & = & 2HPO_3 \\
1\ \text{mole} & & 2\ \text{moles} \\
142\,g & & 160\,g
\end{array}$$

142 g of phosphoric anhydride produce 160 g of the acid
x g of phosphoric anhydride produce 20 g of the acid

$$142 : x = 160 : 20 \qquad x = \frac{142 \times 20}{160} = 17.75\ g$$

To prepare 20 g of metaphosphoric acid 17.75 g of P_2O_5 are required. The quantity of phosphorus required to prepare the 17.75 g of P_2O_5 is:

$$\begin{array}{ccc}
4P + 5O_2 & = & 2P_2O_5 \\
4\ \text{g-atoms} & & 2\ \text{moles} \\
124 & & 284
\end{array}$$

$$124 - 284$$

$$x - 17{,}75 \qquad x = \frac{124 \times 17.75}{284} = 7.75$$

Answer: 7.75 g of phosphorus are required to prepare 20 g of metaphosphoric acid.

Oxygen and water are not accounted for in these calculations.

The solution has been done according to the following schemes:

$$4P \longrightarrow 2P_2O_5 \quad \text{or} \quad 2P \longrightarrow P_2O_5$$
$$P_2O_5 + H_2O \longrightarrow 2HPO_3$$

These can be joined into one scheme:

$$2P \longrightarrow 2HPO_3 \text{ or } P \longrightarrow HPO_3$$

and by using this stoichiometric scheme one can solve the same problem by another method.

Solution:

$$\underset{31}{P} \longrightarrow \underset{80}{HPO_3}$$
$$31\text{ g P} - 80\text{ g } HPO_3$$
$$x - 20\text{ g}$$
$$31 : x = 80 : 20 \quad x = \frac{31 \times 20}{80} = 7.75$$

Answer: 7.75 g of phosphorus.

The method of solving chemical problems by using stoichiometric schemes has a certain advantage over the commonly used method of solving problems from chemical equations, since the calculations are less time-taking.

In making out stoichiometric schemes, one must first see to it that the starting substance and the reaction product have an element in common against which the necessary coefficients can be placed. The number of atoms of the other elements involved is not taken into consideration. The formulas of the starting substance and of the reaction product are connected by an arrow.

Consider an example of determining the main element and making out a stoichiometric scheme.

The starting material used in preparing sulphuric acid is iron pyrite FeS_2. The pyrite is first heated as a result of which ferric oxide Fe_2O_3 and sulphur dioxide SO_2 are formed:

$$4FeS_2 + 11O_2 = 2Fe_2O_3 + 8SO_2$$

The thus prepared sulphur dioxide is then oxidized with atmospheric oxygen into SO_3 (sulphuric anhydride):

$$2SO_2 + O_2 = 2SO_3$$

Finally, sulphuric anhydride reacts with water to form sulphuric acid:

$$SO_3 + H_2O = H_2SO_4$$

If it is necessary to calculate the quantity of sulphuric acid that can be produced from a given quantity of pyrite, sulphur is the main element, since it is present in both the pyrite and the acid. The starting material is iron pyrite, and the reaction product, sulphuric acid. The stoichiometric scheme for solution of the problem is

$$FeS_2 \longrightarrow 2H_2SO_4$$

But whenever it is necessary to determine the quantity of ferric oxide Fe_2O_3 from the quantity of the processed pyrite, iron becomes the main element. The starting material is pyrite FeS_2 and the final product is ferric oxide Fe_2O_3; the stoichiometric scheme for solution of this problem is

$$2FeS_2 \longrightarrow Fe_2O_3$$

Example 3. How many tons of sulphuric acid can be produced from 400 tons of pyrite containing 42 per cent of sulphur?

Solution: Make out the scheme:

$$S \longrightarrow H_2SO_4$$

Calculate the quantity of sulphur in 400 tons of pyrite containing 42 per cent of sulphur:

$$400 \times 0.42 = 168 \text{ tons}$$

Determine the quantity of sulphuric acid that can be produced from 168 tons of sulphur by using the above scheme:

$$\underset{32}{S} \longrightarrow \underset{98}{H_2SO_4}$$

$$32 \text{ tons} - 98 \text{ tons}$$

$$168 \text{ tons} - x \text{ tons}$$

$$x = \frac{168 \times 98}{32} = 514.5$$

Answer: 514.5 tons of sulphuric acid can be produced from 400 tons of iron pyrite containing 42 per cent of sulphur.

Only students experienced in solving chemical problems by the common method (from chemical equations) can pass over to solving chemical problems from stoichiometric schemes.

PROBLEMS

1.47. 36 litres of water were completely decomposed. What quantities in kilograms and litres (at NTP) of hydrogen and oxygen were prepared as a result?

1.48. What quantity in grams of copper oxide CuO is produced by oxidizing (a) 4 g of copper; (b) 8 moles of copper?

1.49. How much oxygen will be liberated by decomposing (a) 86.8 g of mercury oxide; (b) 10 moles of mercury oxide?

Express the answer in grams and litres at NTP.

1.50. What quantity of oxygen in litres at NTP can be obtained by decomposing 10 moles of water?

1.51. What is the volume of oxygen liberated by decomposing 2 kilomoles of water (at NTP)?

1.52. How much magnesium oxide MgO is obtained by burning in oxygen (a) 36 g of magnesium; (b) 1.25 moles of magnesium?

1.53. The resultant products of the interaction between magnesium and carbon dioxide are magnesium oxide MgO and free carbon C in the form of carbon black. Make out the reaction equation. Calculate the quantities of magnesium oxide and carbon that are formed by burning (a) 3 g-atoms of magnesium; (b) 96 g of magnesium.

1.54. How much sulphur dioxide SO_2 can be prepared by burning 10 g-atoms of sulphur? Express your answer in grams, kilogram-molecules, and litres at NTP.

1.55. How much hydrogen can be liberated from hydrochloric acid by acting on it with (a) 6.5 g of zinc; (b) 2 g-atoms of zinc? Express your answer in grams, gram-molecules, and in litres at NTP.

1.56. What quantity in grams of sodium hydroxide NaOH will be formed in the reaction between water and (a) 4.6 g of sodium; (b) one gram-atom of sodium?

1.57. How much hydrogen will be evolved in the reaction between water and potassium taken in amounts (a) 3.9 g; (b) 10 g-atoms? Express the answer in grams, gram-molecules, and litres (at NTP).

1.58. How much KOH is formed in the reaction between 0.9 litre of water and the appropriate quantity of potassium? Express the answer in grams and moles.

1.59. Make out the equation of the reaction between calcium and water. Calculate the number of grams of calcium hydroxide $Ca(OH)_2$ that are formed by the action of 0.1 kg-atom of calcium on the appropriate quantity of water.

1.60. In the reaction between 650 g of commercial zinc and the appropriate quantity of sulphuric acid H_2SO_4, hydrogen was liberated in the air, and $ZnSO_4$ (formed in the reaction) passed into solution. Make out the equation of the reaction and determine the quantities in grams of (a) hydrogen and (b) $ZnSO_4$ that were formed in the reaction (the starting zinc contained 98 per cent of pure metal, the rest being admixtures).

1.61. Quicklime CaO and carbon dioxide CO_2 are formed in calcining limestone. How many tons of quicklime can be prepared from 20 tons of limestone containing 92 per cent of calcium carbonate $CaCO_3$?

1.62. What quantity of mercury oxide HgO should be decomposed to liberate (a) 11.2 litres of O_2 (at NTP); (b) 10 moles of O_2; (c) 320 g of O_2?

1.63. How many grams of magnesium should be burnt to prepare (a) 160 g of magnesium oxide; (b) 16 moles of magnesium oxide?

1.64. How much copper should be oxidized to prepare (a) 40 g and (b) 4 moles of copper oxide?

1.65. What quantity of water should be decomposed to prepare (a) 96 kg of oxygen; (b) 672 litres of oxygen (at NTP); (c) 4 moles of hydrogen; (d) 4.48 litres of hydrogen (at NTP)?

1.66. What quantity of malachite $(CuOH)_2CO_3$ should be completely decomposed to prepare (a) 0.25 mole of cupric oxide; (b) 0.2 mole of water; (c) 224 litres of carbon dioxide (at NTP)?

1.67. What quantity of dissolved copper sulphate $CuSO_4$ will produce 12.8 g of copper by the action of 11.2 g of powdered iron?

1.68. What quantity in grams of copper sulphate will yield 3.2 g of copper by the action on it with the appropriate quantity of zinc?

1.69. Hydrochloric acid and barium sulphate precipitate are formed in the reaction between sulphuric acid and barium chloride solution. Calculate from the reaction equation (1) the quantity in grams of sulphuric acid that reacts with the appropriate quantity of barium chloride to precipitate (a) 2.33 g; (b) 0.5 mole of barium sulphate; (2) the quantity in grams of barium chloride that reacts with the appropriate quantity of sulphuric acid to precipitate (a) 4.66 g; and (b) 3 moles of barium sulphate.

CHAPTER TWO

THE HALOGENS

5. Chlorine and Its Compounds

2.1. What quantity in grams of manganese dioxide reacts with the appropriate quantity of hydrochloric acid to liberate (a) 142 g of chlorine; (b) 8 moles of chlorine; (c) 0.5 mole of chlorine; (d) 2.24 litres of chlorine (at NTP)?

2.2. How many kilograms of ore known as pyrolusite containing 98 per cent of manganese dioxide react with sufficient quantity of hydrochloric acid to liberate (a) 7.1 kg of chlorine; (b) 6 kilomoles of chlorine; (c) 1.25 moles of chlorine; (d) 200 litres of chlorine measured at NTP?

2.3. What quantity of chlorine in (a) gram-molecules; (b) kilograms; (c) litres at NTP will be liberated by the action of the appropriate quantity of hydrochloric acid on 261 kg of pure manganese dioxide?

2.4. What quantity out of (a) 50 g; (b) 0.6 mole of pure manganese dioxide will remain in excess in the reaction with a solution containing 73 g of hydrogen chloride?

2.5. 29 g of pure manganese dioxide were treated with an aqueous solution containing 50 g of hydrogen chloride. What quantity (a) in grams; (b) in gram-molecules; (c) in litres at NTP of chlorine was liberated?

2.6. What quantity of manganese dioxide was spent to obtain 448 litres (at NTP) of chlorine by reacting with sufficient quantity of hydrochloric acid, if the yield of chlorine was 98 per cent of theory?

2.7. The reaction between 174 kg of manganese dioxide and the appropriate quantity of hydrochloric acid yields 140 kg of chlorine. What are the losses of chlorine in the process?

2.8. Chlorine can be prepared by reacting manganese dioxide with sulphuric acid and sodium chloride:

$$MnO_2 + 2H_2SO_4 + 2NaCl = Na_2SO_4 + MnSO_4 + 2H_2O + Cl_2$$

What quantity in grams of manganese dioxide is required to prepare (a) 142 g; (b) 3.5 moles; (c) 179.2 litres at NTP of chlorine?

2.9. One of the laboratory methods for preparing chlorine is the reaction between potassium permanganate $KMnO_4$ and concentrated hydrochloric acid:

$$2KMnO_4 + 16HCl = 2MnCl_2 + 2KCl + 8H_2O + 5Cl_2$$

How many (a) gram-molecules; (b) grams; (c) litres at NTP of chlorine can be prepared from 79 g of $KMnO_4$ and the appropriate quantity of hydrochloric acid?

2.10. How many grams of chlorine can be prepared by reacting 0.5 mole of potassium chlorate with hydrochloric acid according to the following equation:

$$KClO_3 + 6HCl = KCl + 3H_2O + 3Cl_2$$

What volume will this quantity of chlorine occupy at NTP?

2.11. How many (a) gram-molecules; (b) kilogram-molecules; (c) grams of potassium chlorate are required to prepare 30 moles of chlorine by reacting the salt with sufficient quantity of hydrochloric acid?

2.12. The reaction between potassium dichromate $K_2Cr_2O_7$ and concentrated hydrochloric acid is expressed by the following equation:

$$K_2Cr_2O_7 + 14HCl = 2KCl + 2CrCl_3 + 7H_2O + 3Cl_2$$

How many grams of $K_2Cr_2O_7$ react with sufficient quantity of hydrochloric acid if (a) 1.5 moles; (b) 2.13 g; (c) 6.72 litres at NTP of chlorine are liberated?

2.13. What product will be obtained if chlorine is passed through a hot solution of sodium hydroxide? Write down the equation of the reaction.

2.14. What volume (at NTP) will gaseous chlorine occupy if 5 litres of liquid chlorine are evaporated? (Density of liquid chlorine is 1.47 g/cc.)

2.15. What quantity of water is required to absorb the whole quantity of chlorine liberated in the reaction between 2 moles of manganese dioxide and the appropriate amount of hydrochloric acid? In normal conditions one volume of water absorbs 4.6 volumes of chlorine.

2.16. Why must steel containers be thoroughly dried before being filled with liquid chlorine?

2.17. Write down the equations for reactions of burning in chlorine of the following simple substances (parenthesized Roman numerals designate the valence of the element): (a) tin Sn (IV); (b) phosphorus P (III); (c) sodium Na (I). Calculate the mass of the reaction products knowing that 0.2 mole of chlorine is consumed in each case.

2.18. Antimonous chloride $SbCl_3$ and antimonic chloride $SbCl_5$ are formed simultaneously on burning antimony in chlorine. Write the equations of the appropriate reactions and calculate the quantities in grams of antimony that are necessary to prepare (a) 1 mole of antimonous chloride and (b) 0.5 mole of antimonic chloride.

2.19. How many grams of aluminium chloride $AlCl_3$ are formed in the reaction between (a) 5.4 g of aluminium and the appropriate quantity of chlorine; (b) 108 g of aluminium and 355 g of chlorine?

2.20. Iron reacts with chlorine to form ferric chloride $FeCl_3$. Write down the equation of the reaction. Calculate the excess quantity of chlorine in the reaction between 2.8 g of iron and 8 g of chlorine.

2.21. Turpentine $C_{10}H_{16}$ burns in chlorine according to the following equation:

$$C_{10}H_{16}+8Cl_2=16HCl+10C$$

What quantity in grams of free carbon will be liberated per mole of the spent chlorine?

2.22. What quantities in grams of hydrogen and chlorine are required to prepare synthetic hydrogen chloride in amount of (a) 7.3 tons; (b) 10 moles; (c) 448 litres at NTP?

2.23. The daily output of a commercial plant producing synthetic hydrogen chloride is 30 tons. What volume at NTP of hydrogen expressed in cubic metres does the furnace consume per hour?

2.24. What gas and in what quantity will remain unreacted in the reaction between (a) 213 g of chlorine and 8 g of hydrogen; (b) 2 moles of chlorine and 3 moles of hydrogen; (c) 5 litres of chlorine and 4.48 litres of hydrogen at NTP?

2.25. To preclude contamination of hydrochloric acid with chlorine during its synthesis, hydrogen is taken in slightly excessive quantities. What quantity of hydrogen, taken with a 5 per cent excess with respect to the theoretically needed quantity, is required to prepare 25 tons of synthetic hydrogen chloride?

2.26. What quantities of hydrogen and chlorine are required to prepare one ton of a 31 per cent hydrochloric acid on condition that the starting substances do not contain any admixtures and the reaction proceeds to the end?

2.27. What quantities of hydrogen chloride and water are required to prepare (a) 1 kg of a 33 per cent hydrochloric acid; (b) one ton of a 35 per cent hydrochloric acid?

2.28. What quantities of hydrogen and chlorine are required to prepare 100 kg of a 28 per cent hydrochloric acid, if hydrogen is taken in amount 3 per cent greater than theoretically needed?

2.29. Calculate the quantity of chlorine required to prepare 0.5 ton of a 31 per cent hydrochloric acid, if the chlorine losses are 2.5 per cent.

2.30. What quantities in grams of (a) hydrogen chloride; (b) sodium hydrogen sulphate are produced by the reaction between 10 moles of sodium chloride and sufficient quantity of sulphuric acid?

2.31. Calculate the quantities of sodium chloride and sulphuric acid required to prepare (a) 365 g of hydrogen chloride, if the acid salt is produced in the reaction; (b) 240 g of sodium hydrogen sulphate; (c) 8 moles of hydrogen chloride if the neutral salt is produced in the reaction; (d) 10 moles of sodium sulphate. Specify the temperature conditions of each particular reaction.

2.32. 7.3 kg of hydrogen chloride were produced by the reaction between 12.05 kg of sodium chloride contaminated with impurities and the appropriate quantity of sulphuric acid. Calculate the percentage content of admixtures in the sodium chloride.

2.33. 68 kg of hydrogen chloride were prepared from 120 kg of table salt containing 98.5 per cent of sodium chloride. Calculate the yield of hydrogen chloride in per cent of theory.

2.34. 10.95 g of hydrogen chloride were produced by slightly heating a mixture containing sodium chloride and sulphuric acid. Calculate the quantities of (a) sodium chloride and (b) sulphuric acid that took part in the reaction, taking into account that the acid salt was formed in the reaction.

2.35. Which of the substances given below can react with each other on heating to form hydrogen chloride: $KHSO_4$; $AlCl_3$; KCl; H_2SO_4? Develop your reasons.

2.36. What quantities of (a) $CaCl_2$; (b) $NaCl$; (c) $KHSO_4$; (d) $NaHSO_4$ are required to produce 156 g of hydrogen chloride by reacting with sulphuric acid?

2.37. The reaction between sulphuric acid and magnesium chloride yielded 146 g of hydrogen chloride, 10 g of the magnesium chloride remaining unreacted. What quantity of magnesium chloride in per cent of the initial took part in the reaction?

2.38. 0.5 ton of table salt and the appropriate quantity of sulphuric acid were used in the manufacture of hydrochloric acid by the sulphate method. What quantity of a 27 per cent hydrochloric acid can be produced with these reactants?

2.39. 460 kg of table salt containing 97.5 per cent of sodium chloride were spent to produce one ton of a 26 per cent hydrochloric acid by the sulphate method. What is the yield of hydrochloric acid in per cent of theory?

2.40. Table salt and a 91 per cent sulphuric acid were used in the manufacture of hydrochloric acid. What is the daily consumption of sulphuric acid if a commercial plant produces 9.5 tons of a 35.39 per cent hydrochloric acid daily?

2.41. Hydrogen chloride formed by the action of excess quantity of sulphuric acid on 234 g of sodium chloride was dissolved in water. What quantity in grams of an 8 per cent solution of potassium hydroxide will neutralize the prepared solution?

2.42. Hydrogen chloride liberated by the action of sulphuric acid on 14.9 g of potassium chloride was passed into a solution containing 8 g of sodium hydroxide. The solution was then evaporated. What is the mass and the composition of the dry residue?

2.43. In the reaction between aluminium and hydrochloric acid, 3 g of hydrogen were evolved. What quantity of hydrogen chloride took part in the reaction?

2.44. Will 140 ml of hydrochloric acid (density 1.10 g/cc at 15°C) dissolve (a) 13 g of zinc; (b) 20 g of aluminium?

2.45. Calculate the weight of the precipitate prepared by the action of excess quantities of a silver nitrate solution on a solution containing (a) 29 g of sodium chloride; (b) 37 g of potassium chloride.

2.46. How many grams of silver chloride will precipitate on mixing a solution of 0.5 mole of KCl with a solution of 0.75 mole of $AgNO_3$? What substances and in what quantities will remain in solution?

2.47. Write down the equations of all possible reactions by which NaCl can be produced from the following substances: NaOH, Na_2SO_4, HCl and $BaCl_2$.

2.48. How many grams of magnesium oxide will react with hydrochloric acid to produce (a) 3 moles; (b) 4.65 g of magnesium chloride?

2.49. How can (a) NaCl; (b) KCl; (c) $MgCl_2$; (d) $CaCl_2$; (e) $CuCl_2$; (f) $AlCl_3$ be produced from hydrochloric acid? Write down the equations of the reactions.

2.50. Write down the equations of the reactions in which the following transformations occur:

(a) $Al \longrightarrow AlCl_3 \longrightarrow AgCl$

(b) $Mg \longrightarrow MgCl_2 \longrightarrow AgCl$

2.51. To 10 ml of a 16.15 per cent hydrochloric acid added were 5 ml of a 20 per cent solution of potassium hydroxide. What is the colour of litmus in this solution? Develop your reasons and prove the answer by calculations.

2.52. What quantity in grams of potassium chlorate can be produced by the reaction between 12 moles of potassium hydroxide and the required quantity of chlorine? How many grams of water will be produced in the reaction?

2.53. What quantity in grams of potassium chlorate can be produced from 400 g of potassium hydroxide containing 1.8 per cent of admixtures? What quantity in grams of chlorine will be spent in the reaction?

2.54. Will 4 moles of chlorine be sufficient to react with potassium hydroxide to produce 160 g of potassium chlorate?

2.55. What quantity of potassium hydroxide is required to prepare 24.5 g of potassium chlorate?

2.56. 30 g of chlorine and 33.6 g of potassium hydroxide were reacted to produce a certain quantity of potassium chlorate. Which of these two substances and in what quantity remained unreacted?

2.57. Calculate the percentage content of admixtures in a sample of potassium hydroxide, if one mole of potassium chlorate was produced from 342.8 g of this sample by the action of 3 moles of chlorine.

2.58. Write down structural formulas of the following monobasic oxyacids containing chlorine: (a) $HClO$ (hypochlorous acid); (b) $HClO_2$ (chlorous acid); (c) $HClO_3$ (chloric acid); (d) $HClO_4$ (perchloric acid).

2.59. Make out the molecular and structural formulas of a chlorine oxide which is the anhydride of perchloric acid $HClO_4$. Calculate the chlorine content (in per cent) of this oxide.

2.60. As chlorine is passed through a cold solution of sodium hydroxide, a salt of hypochlorous acid is formed alongside with the chloride. The reaction equation is:

$$2NaOH + Cl_2 = NaCl + NaOCl + H_2O$$

What quantity of chlorine is required to react with 160 kg of sodium hydroxide to prepare Javelle water (a mixture of NaCl and NaOCl) in amount corresponding to the reaction equation?

6. Bromine and Its Compounds

2.61. What quantity in grams of bromine is formed by acting with chlorine on (a) 714 g of KBr; (b) 618 g of NaBr; (c) 200 g of $CaBr_2$; (d) 2 moles of $AlBr_3$?

2.62. Bromine can be prepared from sodium bromide by slightly heating it with concentrated sulphuric acid and manganese dioxide. The reaction equation is as this:

$$2NaBr + MnO_2 + 3H_2SO_4 = 2NaHSO_4 + MnSO_4 +$$
$$+ 2H_2O + Br_2$$

What quantities in grams of NaBr and MnO_2 are required to prepare 3 moles of bromine?

2.63. The reaction between potassium bromide KBr, manganese dioxide MnO_2 and sulphuric acid H_2SO_4 (with intense heating) gives potassium sulphate K_2SO_4, manganese sulphate $MnSO_4$, water and bromine Br_2.

What quantity in grams of bromine will be prepared from 4 moles of potassium bromide by the reaction with the appropriate quantities of the other two starting substances?

2.64. Make out the equations of the reactions by which bromine can be obtained from $CaBr_2$, HCl and MnO_2.

2.65. Determine the valence of bromine in the following compounds: $FeBr_3$, KOBr, $Ca(BrO_3)_2$. Write down the structural formulas of these compounds.

2.66. Aluminium burns in an atmosphere of bromine to form aluminium bromide $AlBr_3$. Make out the equation of this reaction and calculate what quantity in grams of aluminium is consumed in the formation of 6 moles of aluminium bromide.

2.67. What quantity of hydrogen bromide can be synthesized from 40 tons of bromine?

2.68. How much hydrogen bromide is formed by the reaction between 2 moles of bromine and the required amount of hydrogen?

2.69. The action of concentrated sulphuric acid on hydrogen bromide yields free bromine Br_2, sulphur dioxide SO_2 and water:

$$2HBr + H_2SO_4 \rightleftarrows Br_2 + SO_2 + 2H_2O$$

What quantity of bromine can be liberated from 3 moles of hydrogen bromide?

2.70. Write down the equation of the reaction in which bromine is displaced from aluminium bromide $AlBr_3$ with chlorine, and calculate the quantity of aluminium bromide that can liberate 1.5 moles of bromine by the action of the appropriate quantity of chlorine.

2.71. What quantity in grams of chlorine can displace all bromine contained in 92 g of magnesium bromide?

2.72. Derive the equation according to which bromine reacts with calcium, and calculate what quantity of calcium bromide $CaBr_2$ can be prepared from 5 moles of bromine and the appropriate quantity of calcium.

2.73. Write down the equation of the reaction for preparing (a) magnesium bromide from hydrobromic acid and magnesium; (b) bromine from hydrobromic acid and manganese dioxide.

2.74. What quantity of silver nitrate will react with 2 moles of sodium bromide?

2.75. A solution containing 11.9 g of potassium bromide was mixed with 20 g of silver nitrate. The AgBr precipitate was separated on a filter. What substance and in what quantity remained in the filtrate?

7. Iodine and Its Compounds

2.76. What quantity in grams of chlorine can displace all iodine contained in 4 moles of sodium iodide?

2.77. What quantity of chlorine will displace 5 moles of iodine from potassium iodide?

2.78. Can all iodine contained in 147 g of calcium iodide be displaced by 30 g of chlorine? Prove your answer by calculations.

2.79. How many grams of iodine can be displaced from 0.4 mole of zinc iodide by (a) the appropriate quantity of chlorine; (b) 64 g of bromine?

2.80. What quantity in grams of silver iodide AgI is precipitated by the action of 1.5 moles of zinc iodide and the appropriate quantity of silver nitrate?

2.81. Natural Chile nitre $NaNO_3$ contains iodine as an admixture (in the form of $NaIO_3$, sodium iodate). To extract iodine from a concentrated solution of Chile nitre, it is acted upon with salts of sulphurous acid, for example Na_2SO_3 (sodium sulphite) and $NaHSO_3$ (sodium bisulphite). The reaction equation is as follows:

$$2NaIO_3 + 2NaHSO_3 + 3Na_2SO_3 = 5Na_2SO_4 + H_2O + I_2$$

What quantity of iodine can be liberated in this case from 198 kg of $NaIO_3$?

2.82. Like bromine, iodine can be prepared by heating a mixture of any iodide, for example of potassium iodide KI, with manganese dioxide MnO_2 and concentrated sulphuric acid. The equation of the reaction is:

$$2KI + MnO_2 + 3H_2SO_4 = 2KHSO_4 + MnSO_4 + 2H_2O + I_2$$

What quantity of iodine can be prepared from 100 moles of potassium iodide by the action of the appropriate quantities of the other starting substances?

8. Fluorine and Its Compounds

2.83. Why cannot fluorine be obtained practically from its compounds by chemical reactions unless electric current is applied?

2.84. Calculate the percentage content of fluorine in the following compounds: (a) hydrogen fluoride; (b) sodium fluoride; (c) calcium fluoride.

2.85. How many (a) grams, (b) gram-molecules, (c) gram-atoms of oxygen are liberated during decomposition of water by 1.9 g of fluorine?

2.86. 8 moles of hydrogen fluoride were formed during decomposition of water by fluorine. What quantity in grams of water was decomposed?

2.87. 8 g of oxygen were liberated during decomposition of water by fluorine. Calculate the quantities in grams of water and fluorine that took part in the reaction.

2.88. The reaction of combination of fluorine with hydrogen is expressed by the following thermochemical equation:

$$H_2 + F_2 = 2HF + 535.91J \text{ (128 kcal)}$$

Is this an exothermic or endothermic reaction? Calculate the magnitude and determine the sign of the heat effect of the reaction in which hydrogen fluoride is obtained in the following quantities: (a) 3 moles; (b) 0.5 mole; (c) 240 kg.

2.89. What quantity of hydrogen fluoride is liberated during the action of sulphuric acid on 4 moles of calcium fluoride?

2.90. 0.48 ton of hydrogen fluoride was obtained by the action of excess sulphuric acid on one ton of calcium fluoride. Determine the yield of the reaction product in per cent of theory.

2.91. What quantity of sulphuric acid is required to prepare hydrogen fluoride by the action on calcium fluoride taken in amounts of (a) 39 g; (b) 2 moles; (c) 1.5 kg?

2.92. 242 kg of hydrogen fluoride were prepared by processing 500 kg of feldspar containing 95 per cent of calcium fluoride. What is the yield of the product in per cent of theory?

9. Laboratory Exercises

2.93. Four test-tubes contain solutions of calcium chloride, hydrochloric acid, potassium iodide, and distilled water. How can each particular substance be identified?

2.94. By using hydrochloric acid (density 1.12 g/cc) prepare its 18.11 per cent solution. Neutralize 20 ml of the solution by a given quantity of sodium hydroxide solution. Knowing the quantity of the sodium hydroxide solution, what is its percentage concentration?

10. Review Problems

2.95. Write down the equations of reactions in which bromine and iodine are displaced by chlorine from the following salts: $MgBr_2$, KI, CaI_2, NaBr, $AlBr_3$.

2.96. What quantity of bromine will be displaced from potassium bromide by 1.5 moles of chlorine?

2.97. What quantity in grams of iodine will be liberated from a solution of potassium iodide by passing 3 litres of chlorine (at NTP) into it?

2.98. Two jars having no labels contain sodium iodide and sodium bromide. Identify the halogen contained in each particular substance and illustrate your answer with the corresponding equations.

2.99. A mixture of manganese dioxide and concentrated hydrochloric acid was heated in a test-tube. A filter paper treated with a solution of potassium iodide and starch was brought to the mouth of the test-tube. The paper turned blue. How can it be explained? Illustrate your answer with the appropriate chemical equation.

2.100. Write down the equation of the reaction between silver nitrate and a solution of (a) potassium chloride;

(b) magnesium chloride; (c) aluminium chloride; (d) sodium bromide; (e) calcium bromide; (f) aluminium bromide.

What particular substance and in what quantity remains in solution, if both reactants are taken in amount of 0.5 mole?

2.101. Hydrogen chloride liberated in the reaction between sulphuric acid and sodium chloride was dissolved in water. The solution was heated with manganese dioxide. The gas liberated in this process was passed through a solution of sodium iodide and displaced 6.3 g of iodine. What quantity of sodium chloride reacted with sulphuric acid?

2.102. What quantity in grams of hydrogen chloride reacted with manganese dioxide, if the chlorine liberated in this process displaced 37.1 g of iodine from a solution of calcium iodide?

2.103. By what reactions can the following transformations be accomplished:

(a) $NaCl \rightarrow HCl \rightarrow Cl_2 \rightarrow HCl \rightarrow ZnCl_2$

(c) $CaCl_2 \rightarrow HCl \rightarrow AlCl_3 \rightarrow HCl \rightarrow Cl_2$

(b) $Cl_2 \rightarrow HCl \rightarrow MgCl_2 \rightarrow HCl$

Write down the equations of these reactions and specify the conditions for each particular reaction.

2.104. In the reaction between 130 g of zinc and the appropriate quantity of hydrochloric acid hydrogen was obtained which was then combined with chlorine. The resultant hydrogen chloride was absorbed by water. The volume of the resultant solution is 10 litres. Calculate the quantity in grams of (a) a 20 per cent solution of KOH required to neutralize 15 ml of this acid solution; (b) a 10 per cent solution of NaOH required to neutralize 20 ml of the acid solution.

2.105. What quantity of hydrogen chloride can be prepared from 11.70 g of sodium chloride if the yield of HCl is 98 per cent of theory?

2.106. What quantity of bromine will be evolved from a solution containing 25 g of NaBr if 2 litres of gaseous chlorine (at NTP) are passed through it?

2.107. What quantity of KCl will be prepared by neutralizing 50 g of a 31 per cent hydrochloric acid with 100 g of a 20 per cent solution of KOH?

CHAPTER THREE

ALKALI METALS

11. Sodium and Potassium

3.1. How many grams of (a) potassium, and (b) sodium will displace all hydrogen from 3 moles of water?

3.2. How many gram-ions of metal are contained in (a) 149 g of KCl; (b) 234 g of NaCl; (c) 3 moles of KNO_3; (d) 20 moles of Na_2SO_4; (e) 0.2 mole of K_2SO_4?

3.3. What quantities of the salts Na_3PO_4 and K_3PO_4 contain equal number of grams of the metals?

3.4. Which of the following natural compounds contains the greatest quantity of sodium: (a) rock salt NaCl; (b) sylvinite $NaCl \cdot KCl$; (c) mirabilite $Na_2SO_4 \cdot 10H_2O$; (d) thenardite Na_2SO_4; (e) glauberite $Na_2SO_4 \cdot CaSO_4$; (f) Chile nitre $NaNO_3$; (g) cryolite $3NaF \cdot AlF_3$, assuming that they contain no admixtures?

3.5. Which of the fertilizers given below are richest in potassium: (a) potassium nitrate KNO_3; (b) sylvine KCl; (c) sylvinite $NaCl \cdot KCl$; (d) carnallite $KCl \cdot MgCl_2 \cdot 6H_2O$; (e) kainite $KCl \cdot MgSO_4 \cdot 3H_2O$?

3.6. Calculate the percentage concentration of solutions prepared by dissolving in one litre of water (a) 8 moles of NaOH; (b) 128 g of KOH; (c) 117 g of NaCl; (d) 4 moles of KCl; (e) 303 g of KNO_3; (f) 2 moles of $NaNO_3$; (g) 284 g of Na_2SO_4; (h) 348 g of K_2SO_4.

3.7. What quantity in grams of sodium hydroxide can be prepared by reacting (a) 53 g of sodium carbonate with a sufficient quantity of milk of lime; (b) 20 moles of sodium carbonate with a sufficient quantity of calcium hydroxide?

3.8. A precipitate falls out on mixing a solution of potassium carbonate with a sufficient quantity of a solution of calcium hydroxide. The mass of the precipitate is 40 g. What quantity of the other reaction product is prepared in this reaction?

3.9. How can the presence of sodium carbonate in sodium hydroxide, and of potassium carbonate in potassium hydroxide, be explained?

3.10. What quantity of caustic soda containing 98 per cent of sodium hydroxide is required to neutralize completely (a) 20 ml of a 24.76 per cent sulphuric acid (density 1.175 g/cc); (b) 30 ml of a 29 per cent hydrochloric acid (density 1.145 g/cc)?

3.11. What quantity of sodium bicarbonate should be used instead of (a) 4 g of sodium hydroxide; (b) 5.6 g of potassium hydroxide; (c) 6.9 g of potassium carbonate; (d) 5.3 g of sodium carbonate to neutralize hydrochloric acid?

3.12. Carbon dioxide formed by the reaction between 69 g of potassium carbonate and a sufficient quantity of hydrochloric acid was passed into a solution containing 40 g of sodium hydroxide. A salt was formed as a result. What is its chemical composition and mass?

CHAPTER FOUR

PERIODIC LAW AND PERIODIC SYSTEM OF ELEMENTS OF D. I. MENDELEYEV. STRUCTURE OF MATTER

12. Periodic Law and Periodic System of Elements

4.1. Write down the symbols of the elements which open and close each period of the system.

4.2. Indicate the boxes in the periodic system where (a) the most typical metal; (b) the most typical nonmetal are located. Develop your reasons.

4.3. Consider the position occupied by each of the elements given below in the periodic system and answer: (a) in which of them is the metallic character the strongest: Na or K; Ca or Zn; Mg or Al; Sn or Pb; Fe or Co; (b) in which of the following elements are the nonmetal properties the strongest: Br or I; Cl or F; Cl or I; S or Se; C or Si; S or Cl; P or S; Si or P?

Develop thoroughly your reasons.

4.4. In which of the elements given in pairs are the basic properties stronger, in rubidium or in cesium; copper or silver; zinc or mercury; barium or mercury; chromium or molybdenum?

In which element are the acidic properties stronger, in chlorine or in bromine; selenium or tellurium; nitrogen or phosphorus? Prove your answer by considering the position of each element in the periodic system.

4.5. Which of the metals given in pairs below forms a more typical base: (a) lithium or rubidium; (b) potassium or copper; (c) calcium or barium; (d) cesium or gold; (e) radium or barium? Develop your reasons.

4.6. By using the periodic system, indicate the highest valence with respect to oxygen of the following elements: tellurium, lead, bismuth, osmium, mercury, chlorine. Write down the formulas of their highest oxides.

4.7. By consulting the periodic system answer the following questions:

(a) What is the valence with respect to hydrogen of fluorine, sulphur, phosphorus, silicon, selenium?

(b) What are the formulas of gaseous compounds of hydrogen with arsenic, nitrogen, tellurium, bromine, carbon?

4.8. Calculate the percentage content of oxygen in the highest oxides of the following elements: (a) manganese, (b) sulphur, (c) nitrogen, (d) silicon, and (e) mercury.

4.9. Determine the percentage content of hydrogen in gaseous compounds of hydrogen with the following elements: (a) iodine, (b) selenium, (c) arsenic, (d) phosphorus, (e) silicon, (f) tin.

4.10. At the present time the highest known oxide of iodine is iodic acid anhydride I_2O_5. Does it correspond to the highest possible (theoretically) oxide of iodine with respect to its composition?

4.11. Copper forms only one compound with iodine which agrees with its position in the periodic system. Write down the formula of this compound.

4.12. Make out formulas of hydroxides of the following elements: rubidium, cesium, sodium, lithium, potassium. Arrange them in a series in order of increasing basic properties.

4.13. Calculate the percentage content of titanium, vanadium, arsenic, zirconium, cadmium, and molybdenum in their highest oxides.

4.14. Calculate the percentage composition of the highest oxides of niobium and tungsten.

4.15. Derive the formulas of selenic and permanganic acids bearing in mind that their molecules contain one molecule of water per molecule of the highest oxide.

4.16. Calculate the percentage content of hydrogen in its compounds with the following elements: germanium, arsenic, selenium, tin, and antimony.

4.17. Write down the equations of the reactions between (a) rubidium hydroxide and hydrogen telluride; (b) radium bromide and silver nitrate; (c) barium selenide and nitric acid.

4.18. What is the percentage content of scandium in scandium nitrate and scandium sulphate?

4.19. The existence of scandium, gallium, germanium and hafnium, and also their properties, were predicted by D. I. Mendeleyev, and discovered in his life-time. Write down the formulas of their (a) highest oxides; (b) compounds with chlorine in which they display their highest valence with respect to oxygen.

4.20. By consulting the periodic table, write down the formulas of (a) chromic acid and potassium chromate; (b) telluric acid and sodium tellurate. Bear in mind that molecules of the said acids contain one molecule of water per molecule of the highest oxide.

13. Radioactivity and Atomic Structure

4.21. Into what element is radium converted as it emits one alpha particle?

4.22. What is the charge on the nucleus of an element which stands (a) in the third group in the third series; (b) in the fourth group in the fourth series; (c) in the sixth group in the fifth series?

4.23. Draw a diagram of structure of the atoms of the elements having the following atomic numbers: (a) 6, (b) 11, and (c) 20.

4.24. How many electrons are contained in the shells of the atoms of the following elements: lithium, nitrogen, neon, magnesium, sulphur, chlorine, calcium, aluminium, chromium? How many valence electrons does each of them contain, and in what electron shells are they present? What is the highest positive valence of the element? What is the negative valence of the element?

4.25. Consider the position of copper, zinc, boron, silicon, argon, and sulphur in the periodic system and answer the following questions: (a) What is the charge on the nucleus of the atom of each element? (b) How many valence electrons are there in their atoms? (c) How many electrons are contained in the outermost shell of the atoms?

4.26. The relationship between the atomic number of an element (Z), its atomic weight (A) and the number of neutrons contained in the nucleus (N) is expressed by the formula

$$Z = A - N$$

Calculate the number of neutrons in the atom of the element having the atomic number of 13.

4.27. Strontium 90, cesium 137 and iodine 131 are the most dangerous radioactive substances that precipitate after nuclear tests in the atmosphere. Write down the chemical symbols of these radioactive isotopes. How many neutrons does the atom of each of them contain?

14. Electronic Theory of Atomic Structure. Atom Nucleus and Its Electron Shells

4.28. How many protons does the nucleus of the atom of (a) phosphorus; (b) sulphur; (c) neon; (d) aluminium; (e) chlorine contain?

4.29. How many nucleons does the atomic nucleus of (a) sodium; (b) silicon; (c) magnesium; (d) oxygen contain?

4.30. How many neutrons does the nucleus of the silicon atom contain if its mass number is 28, and the charge on the nucleus is 14?

4.31. How many neutrons do the atomic nuclei of (a) carbon; (b) nitrogen; (c) sulphur; (d) neon; (e) magnesium; (f) aluminium contain?

4.32. The atomic nucleus of fluorine (at. weight 19) contains 10 neutrons. How many protons does it contain?

4.33. Draw diagrams of atomic structures of the following elements (the charges on their nuclei are given in parentheses): (a) beryllium (4); (b) nitrogen (7); (c) chlorine (17); (d) helium (2); and (e) magnesium (12).

15. Atomic Structure and Valence. Formation of Chemical Compounds and Simple Substances

4.34. Describe schematically the structure of the following ions: (a) Na^+; (b) F^-; (c) Mg^{2+}; (d) S^{2-}; (e) K^+; (f) O^{2-}; (g) Al^{3+}; (h) Cl^-.

4.35. Write down electronic equations of formation of ions out of atoms: (a) lithium Li^+; (b) fluoride F^-; (c) calcium Ca^{2+}; (d) oxygen O^{2-}; (e) aluminium Al^{3+}.

4.36. Designate the charge of ions of the following elements: Ca, S(II), Fe(II), Fe(III), O.

4.37. Write down the electronic equations of the process of formation from the elements of the following ionic compounds: KCl, CaF_2, Na_2S and Al_2O_3.

4.38. Draw atomic structure diagrams to describe schematically the formation of molecules of the following substances: potassium fluoride KF, magnesium chloride $MgCl_2$, aluminium sulphide Al_2S_3, and nitric anhydride N_2O_5.

4.39. Draw diagrams to illustrate the formation of molecules of the following simple substances: hydrogen, oxygen, nitrogen, fluorine.

CHAPTER FIVE

SOLUTIONS. BASIC PRINCIPLES OF THEORY OF ELECTROLYTIC DISSOCIATION

16. Solutions. Solubility

5.1. The solubility of potassium chlorate in 100 g of water at 50°C is 20 g. How many grams of this substance can be dissolved in 500 g of water at the same temperature?

5.2. The solubility of sal ammoniac in 100 g of water at 90°C is 70 g. What quantity in grams of this substance can be dissolved in 500 g of water at the same temperature?

5.3. 300 g of saturated at 60°C aqueous solution contain 157.01 g of potassium nitrate KNO_3. What is the solubility of this substance at 60°C?

5.4. 200 g of saturated at 60°C solution of copper sulphate $CuSO_4 \cdot 5H_2O$ were evaporated to give 57.14 g of dry residue. What is the solubility of blue vitriol in 100 g of water at this temperature?

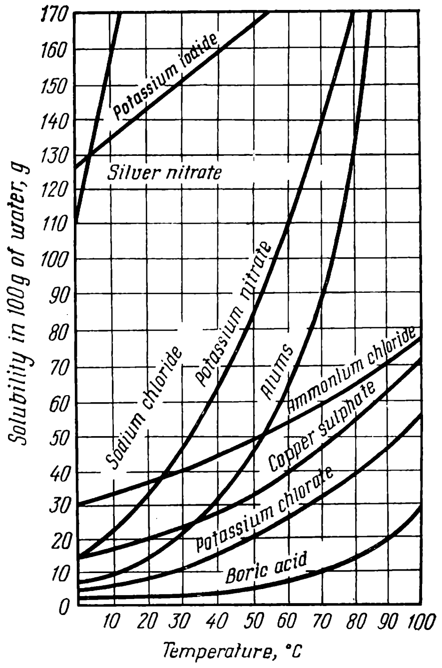
5.5. When a bottle containing fruit drinks, beer, or some other beverage is opened, the liquid produces ample foam. Explain this phenomenon.

5.6. Before boiling, water begins to evolve ample bubbles (of what?) which rise to the surface from the bottom of the heated container. Explain this phenomenon.

5.7. By what two different methods can (a) a saturated solution of a solid substance be turned into an unsaturated one; (b) an unsaturated solution be turned into a saturated solution?

5.8. By using the solubility curves given below determine the solubility in grams per 100 g of water of

Solubility curves



(a) sodium chloride at 100°C; (b) silver nitrate at 100°C; (c) potassium iodide at 30°C; (d) potassium nitrate at 30°C; (e) alums at 70°C; (f) boric acid at 90°C; (g) copper sulphate at 60°C; (h) potassium chlorate at 80°C.

5.9. Construct solubility curves using the following data:

Substance *A*:							
temperature, °C	0	20	40	60		80	100
solubility, g/100 g water	10	25	50	70		90	95
Substance *B*:							
temperature, °C	0	20	40	60		80	100
solubility, g/100 g water	20	35	45	55		70	95
Substance *C*:							
temperature, °C	14	26	38	64		82	
solubility, g/100 g water	40	50	60	80		85	
Substance *D*:							
temperature, °C	0	10	20	30	40	60	100
solubility, g/100 g water	22	28	30	36	40	45	50

5.10. By using the solubility curves, determine which of the following solutions is saturated: (a) 20 g of potassium nitrate in 100 g of water at 30°C; (b) 60 g of blue vitriol in 150 g of water at 60°C; (c) 300 g of potassium iodide in 200 g of water at 40°C.

5.11. What quantity in grams of alums can be prepared by evaporating 190 g of saturated at 70°C aqueous solution of this substance?

5.12. What quantity in grams of potassium nitrate precipitates from 200 g of the solution saturated at 70°C on cooling to 30°C?

17. Percentage Concentration of Solutions

The percentage concentration of a solution is the ratio of the quantity of solute to the quantity of solution expressed in per cent. For example, the percentage concentration of 400 g of a solution containing 80 g of solute is

$$\frac{80}{400}\times 100=20 \text{ per cent}$$

Determining quantities of solute and solvent required to prepare the necessary quantity of solution of wanted percentage concentration.

Example 1. What quantities of sugar and water are needed to prepare 250 g of a 2.5 per cent solution?

Solution: (1) What quantity of sugar is required to prepare 250 g of a 2.5 per cent solution?

$$\frac{250 \times 2.5}{100} = 6.25 \text{ g}$$

(2) What quantity of water is required to prepare the solution? Since the whole solution consists of sugar and water, the quantity of water can be calculated by finding the difference:

$$250 - 6.25 = 243.75$$

Answer: 6.25 g of sugar and 243.75 g of water are required to prepare the 250 g of aqueous solution of sugar.

Determining percentage concentration of solution from given quantities of solute and solvent.

Example 2. What is the percentage concentration of a solution prepared by dissolving 80 g of sugar in 160 g of water?

Solution: (1) Determine the mass of the solution:

$$80 + 160 = 240 \text{ g}$$

(2) What is the percentage concentration of the solution?

$$\frac{80}{240} \times 100 = 33.3 \text{ per cent}$$

Answer: A 33.3 per cent solution is obtained by dissolving 80 g of sugar in 160 g of water.

Determining quantities of solution and solvent from given percentage concentration of the solution and the quantity of solute.

Example 3. What quantity of a 25 per cent solution of a substance can be prepared from 500 g of this substance?

Solution:

500 g of the substance make up 25 per cent by weight of the total solution:

$$\frac{500 \times 100}{25} = 2{,}000 \text{ g} = 2 \text{ kg}$$

The quantity of water required is 2,000 — 500 = 1,500 g = = 1,5 kg.

Answer: 2 kg of a 25 per cent solution can be prepared from 500 g of the substance.

Determining percentage concentration of solution prepared by diluting a given quantity of a solution of known concentration with known amount of water.

Example 4. To prepare a dilute solution of sugar, 600 ml of water were added to 60 g of its 45 per cent solution. What is the percentage concentration of the new solution?

Solution: (1) What quantity of sugar in grams do 60 g of the 45 per cent solution contain?

$$\frac{60 \times 45}{100} = 27 \text{ g}$$

(2) What is the mass of the solution after adding 600 ml of water?

$$60 + 600 = 660 \text{ g}$$

(3) What is the concentration of the resultant solution?

$$27 : 660 = 0.041 = 4.1 \text{ per cent.}$$

Answer: The concentration of the prepared solution is 4.1 per cent.

PROBLEMS

5.13. What quantities in grams of water and table salt are required to prepare (a) 100 g of a 5 per cent solution; (b) 240 g of a 10 per cent solution; (c) 0.5 kg of a 15 per cent solution; (d) 1.2 kg of a 2 per cent solution; (e) 0.4 kg of a 6 per cent solution; (f) 2.2 tons of a 12 per cent solution?

5.14. A physiological saline solution used in medicine for intravenous infusions is actually a 0.9 per cent solution of sodium chloride. What quantities of water and salt are required to prepare 2 kg of such a solution?

5.15. What quantities of water and starting substances are required to prepare 6 kg of a solution which is a mixture of equal quantities of a 4 per cent solution of substance *A* and an 8 per cent solution of substance *B*?

5.16. It is necessary to prepare a solution which is a mixture of equal quantities of a 2 per cent solution of substance *A* and a 5 per cent solution of substance *B*. What quantities of water and the starting substances are needed to prepare 10 kg of such a solution?

5.17. What is the concentration in per cent of a solution prepared by dissolving (a) 90 g of a substance in 180 ml of water; (b) 50 g of a substance in 200 ml of water; (c) 80 g of a substance in 240 ml of water? The density of water is 1 g/ml or 1 kg/litre.

5.18. A solution of barium chloride $BaCl_2$ containing 50 g of solute in 2 litres of water is used in agriculture as an insecticide. What is the concentration of such a solution?

5.19. Three substances were dissolved in one litre of water. The quantities of the dissolved substances were 20, 80 and 60 g. Calculate the percentage concentration of each substance in the solution.

5.20. What quantity of sugar is contained in (a) 1 kg of a 20 per cent solution; (b) 0.5 kg of a 15 per cent solution; (c) 3 kg of a 2 per cent solution; (d) 200 g of a 0.5 per cent solution; (e) 400 g of a 1.2 per cent solution?

5.21. What quantity of a 15 per cent solution can be prepared from 300 g of a substance? What quantity of water is required for the purpose?

5.22. Blue vitriol is used to control fungal diseases in plants. A 0.8 per cent solution of $CuSO_4$ is usually used for the purpose. What quantity of the fungicide solution can be prepared from 400 g of blue vitriol $CuSO_4 \cdot 5H_2O$? What quantity of water is required?

5.23. What quantity of iodine tincture (a 10 per cent alcoholic solution of iodine) can be prepared from 3 g of crystalline iodine? What quantity of alcohol is required?

5.24. What quantity of a 20 per cent solution can be prepared from (a) 40 g; (b) 6 g; (c) 0.2 kg; (d) 1.2 kg; (e) 2.5 kg of a substance? What quantity of water is required in each case?

5.25. 216 ml of water were added to 120 g of a 28 per cent solution of a salt. What is the percentage concentration of the resultant solution?

5.26. 150 ml of water were added to 180 g of a 32 per cent solution of sugar. Calculate the percentage concentration of the obtained solution.

5.27. What is the percentage concentration of a solution prepared by adding 0.5 litre of water to (a) 200 g of a 25 per cent solution; (b) 150 g of a 30 per cent solution; (c) 0.5 kg of a 40 per cent solution?

5.28. How can a 5 per cent solution of sugar be prepared from 2 kg of a 40 per cent solution?

18. Determining Quantities of Acids and Alkalis in Given Quantities of Solutions from Density of the Starting Substance

Special tables (see Appendix) are used for determining the required quantities of substances while preparing solutions of different substances of the wanted density. In Tables 2, 3 and 4, the densities of substances are tabulated in one column, while the other column (to the right) gives the corresponding content of the substances in aqueous solutions (in per cent). Once the percentage concentration of a solution is known, it is easy to determine the density of the solution, and vice versa. For example, the percentage concentration of sulphuric acid, whose density is 1.8400 g/cc (see Table 4) is 95.60 per cent. This means that 100 g of the acid solution having the above density contain 95.6 g of H_2SO_4 and 4.4 g of H_2O. The density of a 65.30 per cent nitric acid (see Table 3) is 1.400 g/cc.

The density of a substance corresponds to the mass of its one millilitre expressed in grams. For example, if a 23.82 per cent hydrochloric acid has the density of 1.12 g/cc this means that the mass of 1 ml of the acid is 1.12 g. The mass of 100 ml of the acid is 112 g. The quantity of hydrogen chloride HCl contained in 112 g of the acid is 26.738 g. This is obvious from the following calculations:

100 g of the acid (density 1.12 g/cc) contain 23.82 g of HCl
112 g of the acid (density 1.12 g/cc) contain x g of HCl

Solving by the proportion method:

$$\frac{100}{112}=\frac{23.82}{x}$$

whence

$$x=\frac{112\times 23.82}{100}=26.738 \text{ g}$$

Example 1. What quantity of hydrogen chloride is dissolved in 50 ml of a 38.16 per cent hydrochloric acid?

Solution: The density of hydrochloric acid having the above concentration is 1.195 g/cc (see Table 2). This means that the mass of 1 ml of the acid is 1.195 g, and 50 ml weigh 59.750 g (1.195 × 50 = 59.750).

100 g of the 38.16 per cent acid contain 38.16 g of HCl
59.75 g of this acid contain x g of HCl

By using the proportion method we have:

$$100 : 59.75 = 38.16 : x$$

Solving for x:

$$x = \frac{59.75 \times 38.16}{100} = 22.809$$

Answer: 50 ml of the 38.16 per cent hydrochloric acid contain 22.809 g of hydrogen chloride, the rest being water.

Example 2. Determine approximately the percentage concentration of a solution of nitric acid containing three volumes of water per one volume of concentrated nitric acid having the density of 1.400 g/cc.

Solution: (1) What is the percentage concentration of nitric acid having the density of 1.4 g/cc?

Find the answer in Table 3. The concentration of HNO_3 having the density of 1.4 g/cc is 65.3 per cent.

(2) What quantity in grams of HNO_3 is contained in 1 ml of concentrated nitric acid?

Three ml of water are mixed with 1 ml of concentrated HNO_3. The mass of 1 ml of concentrated HNO_3 is 1.4 g. The quantity of HNO_3 contained in 1 ml of concentrated nitric acid is

$$1.4 \times 0.653 = 0.9142 \text{ g}$$

(3) What is the mass of the solution?

$$3 + 1.4 = 4.4 \text{ g}$$

(4) What is the approximate concentration of the solution?

$$0.9142 : 4.4 \approx 0.2077 \approx 20.77 \text{ per cent.}$$

Answer: The concentration of the nitric acid is about 20.77 per cent.

Example 3. It is necessary to prepare 0.5 kg of a 10 per cent solution of sodium hydroxide from a 30 per cent solution of the alkali.

Solution: (1) What quantity in grams of sodium hydroxide should be contained in 500 g of a 10 per cent solution?

$$500 \times 0.1 = 50 \text{ g}$$

(2) What quantity of the starting 30 per cent alkali solution contains 50 g of sodium hydroxide?

50 g of NaOH make up 0.3 part of the total solution. The quantity of the starting solution is then

$$50 : 0.3 \approx 166.67 \text{ g}$$

(3) What volume do 166.67 g of a 30 per cent alkali solution occupy?

$$166.67 : 1.332 = 125.13 \text{ ml}$$

(4) What quantity of water is required to prepare 0.5 kg of a 10 per cent alkali solution?

$$500 - 166.67 = 333.33 \text{ g}$$

Answer: To prepare 0.5 kg of a 10 per cent solution ol sodium hydroxide, 125.13 ml of a 30 per cent alkali solution and 333.33 ml of water are required.

PROBLEMS

5.29. What quantity of hydrogen chloride is dissolved in 20 ml of hydrochloric acid of the following concentration (in per cent): (a) 28.14; (b) 12.19; (c) 27.66?

5.30. What quantity of nitric acid is contained in 50 ml of its aqueous solution, the concentration of which is (a) 32.36 per cent; (b) 10.68 per cent; (c) 1.44 per cent?

5.31. What quantity of sodium hydroxide is contained in 40 ml of its aqueous solution the concentration of which is (a) 28 per cent; (b) 32 per cent; (c) 12 per cent?

5.32. Calculate the approximate percentage concentration of hydrochloric acid containing three volumes of water per volume of the concentrated acid having the density of (a) 1,19; (b) 1,2; (c) 1.18 g/cc.

5.33. Calculate (approximately) the percentage concentration of a solution of sulphuric acid containing 4 volumes of water per volume of concentrated acid having the density of (a) 1.84; (b) 1.76; (c) 1.6 g/cc.

5.34. It is necessary to prepare 2 kg of a 4 per cent solution of potassium hydroxide from a solution of KOH the percentage concentration of which is (a) 1.310; (b) 1.24; (c) 1.1. What quantities of water and alkali should be taken for the purpose?

5.35. What quantities of a 32 per cent solution of sodium hydroxide and water should be taken to prepare 3 kg of an 8 per cent solution of NaOH?

5.36. What quantity in grams of sodium sulphite Na_2SO_3 should be taken to prepare 2.5 litres of an 8 per cent solution the density of which is 1.075 g/cc?

19. Mixing Rule

The following example will explain the essence of the mixing rule.

Two solutions of sugar of different concentration are available. Let the concentration of one of them be C_1 and of the other C_2. A new solution of the required concentration C should be composed out of them.

In what proportion should the starting solutions be mixed if $C_1 > C > C_2$?

Let us assume that 100 g of the solution of the required concentration C should be prepared. 100 g of the first solution (of stronger concentration) will contain sugar $(C_1 - C)$ g greater than 100 g of the desired solution. (One gram of this solution will contain sugar $\frac{C_1 - C}{100}$ g greater than one gram of the desired solution.)

But 100 g of the other solution (of weaker concentration) will contain sugar $(C - C_2)$ g less than 100 g of the desired solution. (One gram of this solution contains $\frac{C - C_2}{100}$ g of sugar less than one g of the desired solution.)

Let the number of grams of the first solution required to prepare the sugar solution of the desired concentration be x. Then the quantity of sugar in this solution will be $\frac{C_1 - C}{100}\, x$ g greater than in the desired solution. If the number of grams of the second solution is y, then it will contain sugar $\frac{C-C_2}{100}y$ g less than the desired solution.

In the preparation of the solution of the wanted concentration, part of sugar passes from the solution of stronger concentration into the solution of weaker concentration, that is

$$\frac{C_1-C}{100}x=\frac{C-C_2}{100}y$$

$$(C_1-C)\,x=(C-C_2)\,y$$

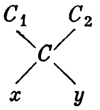
It follows therefore that

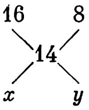
$$x : y = (C - C_2) : (C_1 - C)$$

Hence, the quantities of the starting solutions should be inversely proportional to the differences between the concentrations of the desired solution and the solutions having stronger and weaker concentration. This should be borne in mind while preparing solutions of the required concentration.

Example 1. The concentration of one solution of sugar is 16 per cent, and of the other, 8 per cent. In what weight ratio should these solutions be mixed to prepare a 14 per cent solution of sugar?

Solution: The difference between the concentrations of the first solution and of the required solution is 2 (i.e. $C_1 - C = 16 - 14 = 2$), and the difference between the concentrations of the required and of the second solution is 6 (i.e. $C - C_2 = 14 - 8 = 6$):





where

$$x = C - C_2 \qquad x = 14 - 8 = 6$$

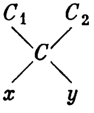
$$y = C_1 - C \qquad y = 16 - 14 = 2$$

$$x : y = 6 : 2 = 3 : 1$$

Answer: To prepare a 14 per cent solution of sugar, it is necessary to take three parts of a 16 per cent solution per one part of an 8 per cent solution.*

Example 2. In what weight ratio should a 30 per cent solution and water be taken to prepare a 20 per cent solution?

Solution:



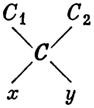
$$C_1=30, \quad C_2=0, \quad C=20$$
$$x=C-C_2=20-0=20$$
$$y=C_1-C=30-20=10$$
$$x:y=20:10=2:1$$

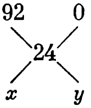
Answer: To prepare a 20 per cent solution, two parts of a 30 per cent solution should be taken per part of water.

Other problems can also be solved by making use of the mixing rule.

Example 3. A sample of commercial caustic potash containing 8 per cent of admixtures is available. In what weight ratio should the caustic potash and water be taken to prepare a 24 per cent solution of KOH?

Solution: The given sample of caustic potash contains 92 per cent of pure KOH (100 — 8 = 92), water contains 0 per cent of KOH. Hence, $C_1 = 92$, $C_2 = 0$, $C = 24$.





$$x = C - C_2 \quad x = 24 - 0 = 24 \text{ (parts by weight)}$$
$$y = C_1 - C \quad y = 92 - 24 = 68 \text{ (parts by weight)}$$
$$x : y = 24 : 68 = 6 : 17$$

Answer: To prepare a 24 per cent solution of potassium hydroxide, 6 parts by weight of caustic potash should be mixed with 17 parts by weight of water.

Example 4. In what weight ratio should dry caustic soda containing 94 per cent of sodium hydroxide and a 12 per cent solution of sodium hydroxide be taken to prepare a 40 per cent solution of NaOH?

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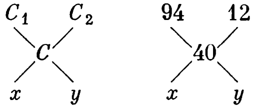
* If a concentrated solution is diluted with water, C_2 should be assumed to be 0 ($C_2 = 0$ per cent).

Solution:

$$C_1 = 94, \quad C_2 = 12, \quad C = 40$$

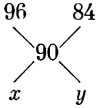


$$x = C - C_2 \quad x = 40 - 12 = 28$$
$$y = C_1 - C \quad y = 94 - 40 = 54$$
$$x : y = 28 : 54$$
$$x : y = 14 : 27$$

Answer: To prepare a 40 per cent solution of sodium hydroxide, dry alkali containing 94 per cent of sodium hydroxide and a 12 per cent solution of the alkali should be taken in the proportion of 14 : 27 (by weight).

Example 5. In what weight ratio should two samples of chalk, one containing 96 and the other 84 per cent of calcium carbonate, be taken to prepare a mixture containing 90 per cent of calcium carbonate $CaCO_3$?

Solution:

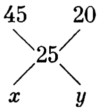


$$x = 90 - 84 = 6$$
$$y = 96 - 90 = 6$$
$$x : y = 1 : 1$$

Answer: To prepare a mixture containing 90 per cent of $CaCO_3$, equal quantities of the two starting samples of chalk should be mixed.

Example 6. In what ratio should two potassium fertilizers, one containing a 45 per cent and the other a 20 per cent potassium salt, be taken in order to prepare a 25 per cent potassium fertilizer?

Solution:

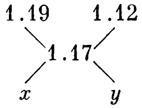


$$x = 25 - 20 = 5$$
$$y = 45 - 25 = 20$$
$$x : y = 5 : 20$$
$$x : y = 1 : 4$$

Answer: To prepare a 25 per cent potassium fertilizer, the first and the second salts should be mixed in proportion of 1 : 4.

The same rule can be used for calculations in cases where the density of solutions is specified. If water is used for dilution (or dissolution) of substances, its density in the scheme should be designated by unity. For example, the starting solutions are hydrochloric acid having the density of 1.12 g/cc and hydrochloric acid with the density of 1.19 g/cc. What volumes of the acids should be mixed together to prepare hydrochloric acid having the density of 1.17 g/cc?

Solution:

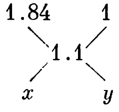


$$x = 1.17 - 1.12 = 0.05$$
$$y = 1.19 - 1.17 = 0.02$$
$$x : y = 0.05 : 0.02 = 5 : 2$$

Answer: To prepare the acid of the required concentration, it is necessary to take 5 volumes of concentrated acid having the density of 1.19 g/cc per 2 volumes of the acid having the density of 1.12 g/cc.

Example 7. What quantities of sulphuric acid having the density of 1.84 g/cc and water should be mixed to prepare sulphuric acid having the density of 1.1 g/cc?

Solution:



$$x = 1.1 - 1 = 0.1$$
$$y = 1.84 - 1.1 = 0.74$$
$$x : y = 0.1 : 0.74$$
$$x : y = 10 : 74$$

It follows therefore that 10 volumes (litres, millilitres) of the acid having the density of 1.84 g/cc should be mixed with 74 volumes of water to prepare 84 volumes of a solution of the required concentration.

The quantity of the starting sulphuric acid is calculated from the ratio:

84 litres of solution are prepared from 10 litres of the starting acid

9 litres of solution are prepared from x litres of the starting acid

$$x = \frac{9 \times 10}{84} = 1.07 \text{ litres}$$

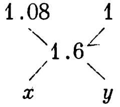
The quantity of water: 9 — 1.07 = 7.93 litres.

Answer: To prepare 9 litres of sulphuric acid of the required concentration 1.07 litres of the available sulphuric acid should be added to 7.93 litres of water.*

The field of application of the mixing rule can be widened by introducing negative values into it.

Example 8. 10 litres of sulphuric acid having the density of 1.08 g/cc are available. To what volume should it be evaporated in order to prepare the acid having the density of 1.6 g/cc?

Solution:



$$x = 1.6 - 1 = 0.6$$
$$y = 1.08 - 1.6 = -0.52$$
$$x : y = 0.6 : (-0.52)$$
$$x : y = 60 : (-52)$$

The calculation shows that 52 litres of water should be evaporated from each 60 litres of the dilute acid having the density of 1.08 g/cc. The result will be 8 litres of a stronger acid, namely, having the density of 1.6 g/cc. Hence, 10 litres of H_2SO_4 having the density of 1.08 g/cc should be evaporated to the volume of 1.33 litres which becomes vivid from the following calculations:

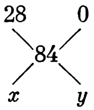
$$\begin{array}{l} 60 - 8 \\ 10 - x \end{array} \qquad x = \frac{8 \times 10}{60} \approx 1.33$$

Answer: the acid should be evaporated to about 1.33 litres.

Example 9. A 28 per cent solution of a salt should be evaporated to the concentration of 84 per cent.

Find: (a) the quantitative ratio of the starting solution and the water that should be removed by evaporation; (b) the quantity in kilograms of the starting solution that should be taken to prepare 2 kg of the 84 per cent solution?

Solution:



$$x = 84 - 0 = 84, \quad y = 28 - 84 = -56$$
$$x : y = 84 : (-56)$$
$$x : y = 3 : (-2)$$

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[*] If the concentrations of solutions in the condition of the problem are expressed in weight units, the answer will be expressed in the same units (grams, kilograms, etc.).

The answer is expressed in units of volume (litres, millilitres, etc.) if the concentrations of the starting substances are expressed in the same units.

It follows from the calculation that (a) two parts of water should be evaporated from three parts of the starting solution; (b) 4 kg (6 — 2 = 4) of water should be removed from 6 kg of the starting solution by evaporation in order to prepare 2 kg of the required 84 per cent solution. It follows from the calculations:

$$\begin{array}{c} 84-28 \\ x-2 \end{array} \qquad x=\frac{84\times 2}{28}=6$$

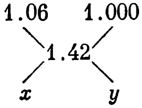
The quantity of water that should be evaporated is

$$6-2=4$$

Answer: 4 kg of water should be removed from 6 kg of the starting solution.

Example 10. A solution having the density of 1.06 g/cc should be evaporated to increase its concentration (to 1.42 g/cc). What is the ratio of volumes of the starting solution and water that should be removed from it by evaporation? What quantity in litres of the starting solution should be taken and what quantity in litres of water should be removed from it to prepare 2 litres of a solution having the density of 1.42 g/cc?

Solution:



$$\begin{aligned} x&=1.42-1.000=0.42 \\ y&=1.06-1.42=-0.36 \\ x:y&=0.42:(-0.36) \\ x:y&=7:(-6) \end{aligned}$$

The above calculations show that in order to prepare a stronger solution (density of 1.42 g/cc) it is necessary to remove 6 volumes of water from 7 volumes of the starting solution. The result will be one volume of the solution of the wanted concentration. To prepare 2 litres of the concentrated solution, 14 litres of the starting solution should be taken and 12 litres of water evaporated from it:

$$\begin{array}{c} 7-1 \\ x-2 \end{array} \qquad x=\frac{7\times 2}{1}=14$$

Answer: 7 : 6; 14 litres of the starting solution; 12 litres of water.

PROBLEMS

5.37. In what quantitative ratio should a 80 per cent and a 14 per cent solution of nitric acid be mixed to prepare a solution having the concentrations of (a) 50 per cent; (b) 20 per cent; (c) 32 per cent?

5.38. In what ratio should water and commercial sodium hydroxide containing (a) 8 per cent; (b) 12 per cent; and (c) 20 per cent of admixtures be mixed to prepare a 16 per cent solution of sodium hydroxide?

5.39. In what ratio should a 22 per cent solution of glucose and water be mixed to prepare a solution having the concentration of (a) 4 per cent; (b) 8 per cent; (c) 2.2 per cent?

5.40. In what ratio should sugar solutions having the concentrations of 50 and 15 per cent be mixed to prepare a new solution having the concentration of (a) 25 per cent; (b) 40 per cent; (c) 20 per cent?

5.41. In what ratio should substances be taken to prepare:

(a) a 40 per cent solution from a 50 and a 20 per cent solution;

(b) a 7 per cent solution from a 17 and a 5 per cent solution;

(c) an 8 per cent solution from a 12 per cent solution and water?

5.42. In what volume ratio should solutions be mixed in order to prepare solutions having (a) the density of 1.235 g/cc from the starting solutions having the densities of 1.410 and 1.135 g/cc; (b) the density of 1.125 g/cc from the starting solutions having the densities of 1.4 and 1.1 g/cc; (c) the density of 1.10 g/cc from a solution having the density of 1.25 g/cc and water?

5.43. In what ratio should commercial caustic potash containing 96 per cent of KOH and a solution of potassium hydroxide having the concentration of (a) 47.7 per cent, (b) 27 per cent be mixed to prepare (in all the three cases) a 50 per cent solution of the alkali?

5.44. A 15 per cent solution of sodium hydroxide is available. The concentration of the solution should be increased to 40 per cent by adding caustic soda containing 80 per cent of NaOH (the rest being admixtures). In what ratio should the alkali solution and the caustic soda be mixed to prepare the required 40 per cent solution of NaOH?

5.45. Green vitriol $FeSO_4 \cdot 7H_2O$ contains 20.14 per cent of iron. In what ratio should the vitriol and water be mixed to prepare a solution containing 5 per cent of iron?

5.46. What quantity of water should be removed from 20 kg of a 30 per cent solution of sugar to raise the concentration to 50 per cent? What will be the mass of the new solution?

5.47. A 12 per cent solution of a salt is available. Its concentration should be increased by boiling to 36 per cent. Calculate (a) the ratio of the starting solution to the water to be removed; (b) the quantities in kilograms of the starting solution that should be taken and of the water to be removed by evaporation in order to prepare 15 kg of a 36 per cent solution.

5.48. Calculate the quantities of chemically pure sodium chloride and a 12 per cent solution of sodium chloride that should be mixed to prepare 15 kg of a 20 per cent solution.

5.49. In what volume ratio should concentrated hydrochloric acid having the density of 1.19 g/cc and water be mixed to prepare a solution of the acid having the density of 1.01 g/cc?

5.50. Concentrated sulphuric acid having the density of 1.84 g/cc is available. Eight litres of the so-called battery acid having the density of 1.28 g/cc should be prepared. What quantities of water and the acid should be mixed for the purpose?

5.51. 42 litres of phosphoric acid having the density of 1.2 g/cc are available. What quantity of water should be boiled out from the solution to obtain a solution having the density of 1.54 g/cc?

5.52. What quantities of two samples of superphosphate, one containing 14 and the other 22 per cent of P_2O_5, should be mixed to prepare 400 kg of the fertilizer containing 20 per cent of P_2O_5? What is the ratio of the two samples in the mixture?

5.53. A cement mixture containing 35 per cent of cement (the rest being sand) is available. In what ratio should the mixture be mixed with pure cement to prepare a new mixture containing 75 per cent of cement?

5.54. Two potassium salts, one containing 25 and the other 35 per cent of potassium, are available. In what ratio should these salts be mixed to prepare a fertilizer containing 30 per cent of potassium?

5.55. A 6 per cent solution of formaldehyde should be prepared. In what ratio should a 40 per cent commercial formaldehyde and water be mixed?

20. Laboratory Exercises (Preparation of Solutions)

5.56. Prepare 250 g of an 8 per cent solution of copper sulphate $CuSO_4$ from blue vitriol $CuSO_4 \cdot 5H_2O$.

5.57. Prepare 150 g of a 2 per cent solution of potassium chloride KCl.

5.58. Prepare a 29 per cent solution of sugar from 0.1 litre of water and the required quantity of sugar.

5.59. Prepare a 1.5 per cent solution from 150 g of a 4 per cent solution of table salt.

21. Molar Concentration of Solutions

The molar concentration, or simply molarity, of solution is the number of gram-molecules (moles) of solute contained in one litre of solution.

A solution one litre of which contains one mole of solute is called molar, a solution containing 0.5 mole is a semimolar solution, 0.1 mole, a decimolar solution, etc.

The molarity of solution is designated by the letter *M* preceded by a coefficient designating the molarity, e.g. 2 *M* designates a solution containing two moles of solute per litre of solution, 0.1 *M* designates a decimolar solution, 0.01 *M* designates a centimolar solution, etc.

To determine the molarity of a solution the number of grams of solute contained in one litre of solution should be divided by the gram-molecular weight of the substance.

Determining quantities of solute and water required to prepare a given quantity of solution of the required molar concentration.

Example 1. What quantities in grams of sodium sulphate Na_2SO_4 and water should be taken to prepare 0.25 litre of a decimolar solution?

Solution: The molecular weight of Na_2SO_4 is 142 g, hence one mole weighs 142 g, and 0.1 mole, 14.2 g.

1 litre of a 0.1 M solution contains 14.2 g

0.25 litre of a 0.1 M solution contains x g

By using the proportion method:

$$1 : 0.25 = 14.2 : x$$

and solving for x:

$$x = \frac{0.25 \times 14.2}{1} = 3.55$$

Answer: To prepare 0.25 litre of a decimolar solution of sodium sulphate, 3.55 g of Na_2SO_4 should be dissolved in 246.45 ml (250 — 3.55 = 246.45) of water.*

Determining molar concentration of solution from the given quantity of solute and known volume of solution.

Example 2. Two litres of nitric acid solution contain 12.6 g of HNO_3. Calculate the molar concentration of the solution.

Solution: The molecular weight of HNO_3 is 63, the gram-molecular weight is 63 g.

(1) What quantity of HNO_3 is contained in 1 litre of the solution?

2 litres of the solution contain 12.6 g

1 litre of the solution contains x g

By using the proportion method we have:

$$2 : 1 = 12.6 : x$$

whence

$$x = 12.6 : 2 = 6.3 \text{ g}$$

(2) What is the molarity of the HNO_3 solution?

$$6.3 : 63 = 0.1$$

Answer: The given solution of nitric acid is decimolar.

Solutions of various substances having the same molar concentration are known as equimolecular solutions.

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* If a measuring flask is used for dissolving, the sample is first dissolved in a small quantity of water and then water is added to the mark.

Equal volumes of equimolecular solutions contain equal number of gram-molecules, and hence equal number of molecules of solute.

PROBLEMS

5.60. What is the molar concentration of a solution containing in one litre (a) 175.5 g of sodium chloride NaCl; (b) 49 g of sulphuric acid H_2SO_4; (c) 10 g of sodium hydroxide NaOH; (d) 112 g of potassium hydroxide KOH; (e) 40 g of copper sulphate $CuSO_4$; (f) 94.5 g of nitric acid HNO_3?

5.61. What quantity in grams of each of the substances given below should be taken to prepare 2 litres of a 0.25 *M* solution of (a) glucose $C_6H_{12}O_6$; (b) phosphoric acid H_3PO_4; (c) nitric acid HNO_3; (d) saltpetre $NaNO_3$; (e) potash K_2CO_3; (f) magnesium sulphate $MgSO_4$?

Calculate the quantities of water required in each particular case.

5.62. What quantity of sugar $C_{12}H_{22}O_{11}$ should be taken to prepare a 0.1 *M* solution in amounts of (a) 1 litre; (b) 10 litres; (c) 1.25 litres; (d) 2.4 litres; (e) 6 litres; (f) 0.75 litre?

5.63. What volume of a 1 *M* solution of hydrochloric acid contains (a) 3.65 g; (b) 0.365 g; (c) 365 g of hydrogen chloride?

5.64. What volume of a 0.1 *M* solution contains (a) 19.6 g; (b) 4.9 g; (c) 2.45 g of H_2SO_4?

5.65. What volume of a 1 *M* solution contains (a) 120 g; (b) 4 g; (c) 0.8 g of NaOH?

5.66. What volume of a 0.02 *M* solution contains (a) 1.12 g; (b) 3.36 g; (c) 4.48 g of KOH?

5.67. What volume of a 0.1 *M* solution contains 7.1 g of sodium sulphate?

5.68. What is the molarity of an alkali solution containing (a) 0.037 g of $Ca(OH)_2$ in 250 ml; (b) 20 g of NaOH in 200 ml; (c) 1.12 g of KOH in 0.5 litre?

5.69. What is the molarity of an acid solution containing (a) 7.3 g of HCl in 100 ml; (b) 75.6 g of HNO_3 in 1.2 litres; (c) 14.7 g of H_2SO_4 in 1 litre?

5.70. What is the molarity of a salt solution containing (a) 4.41 g of NaCl in 0.75 litre; (b) 34.8 g of K_2SO_4 in 2 litres; (c) 31.8 g of Na_2CO_3 in 0.1 litre?

5.71. 100 ml of a 0.2 *M* solution of KOH were mixed with 200 ml of a 0.25 *M* solution of HNO_3. What solution was taken in excess and in what amount?

5.72. What is the molarity of concentrated sulphuric acid having the density of (a) 1.84 and (b) 1.7 g/cc?

5.73. What is the molarity of a solution of nitric acid having the following percentage concentration: (a) 33.82; (b) 20.23; (c) 47.49?

5.74. Calculate the molarity of a solution of sodium hydroxide the density of which is (a) 1.31; and (b) 1.56 g/cc?

5.75. The interaction between hydrochloric acid and silver nitrate is expressed by the equation

$$AgNO_3 + HCl = AgCl \downarrow + HNO_3$$

Calculate the volume of a 20.01 per cent solution of the acid by which all silver can be precipitated from 100 ml of a 0.1 *M* solution of $AgNO_3$.

22. Equivalent Weight. Gram-Equivalent

The equivalent weight of an element is the weight of the element which will react without residue with eight equivalent weights (or eight parts by weight) of oxygen or with one equivalent weight (or one part by weight)* of hydrogen, or will replace them in compounds.

Like atomic and molecular weights the equivalent weight is measured in carbon units. The quantity of grams of a substance (or an element) equal numerically to its equivalent weight is known as gram-equivalent (g-equiv); if the quantity is measured in millilitres, then it will be milligram-equivalent (mg-equiv), etc.

Elements combine with one another (or replace one another in compounds) in quantities proportional to their equivalent weights (the law of equivalent weights):

$$E_1 : E_2 = m_1 : m_2$$

As a rule, the equivalent weight of an element is calculated on the basis of analytical data or from the results of the synthesis of a compound from simple substances.

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* To be more exact, 1.008 parts by weight.

Example 1. Determine the gram-equivalent of calcium knowing that its 5 g combine with 2 g of oxygen.

Solution: Taking into consideration that one gram-equivalent of oxygen weighs 8 g, and using the law of equivalent weights, we can make out the proportion:

$$\text{Equivalent weight of calcium} : 8 = 5 : 2$$

Whence:

$$\text{a gram-equivalent of calcium} = 8 \times 5 : 2 = 20$$

Answer: the gram-equivalent of calcium weighs 20 g.

Example 2. Determine the gram-equivalent of aluminium knowing that its 0.45 g displaces 0.05 g of hydrogen from acids.

Solution: Taking into consideration that one gram-equivalent of hydrogen weighs 1 g, and making use of the law of equivalent weights, make out the proportion:

$$E.\,w._{Al} : 1 = 0.45 : 0.05$$

whence:

$$E.\,w._{Al} = 1 \times 0.45 : 0.05 = 9$$

Answer: one gram-equivalent of aluminium weighs 9 g.

The equivalent weight of a compound is the weight of the substance which will react without residue (combine or displace completely) with one equivalent weight of hydrogen (or oxygen) or, in general, with one equivalent weight of any other substance.

To determine the equivalent weight of a base, its molecular weight (*M*) should be divided by the valence of the metal (or the number of the hydroxyl groups). For example, the equivalent weight of potassium hydroxide KOH is 56, because its molecular weight is 56 and the valence of potassium is 1. The equivalent weight of aluminium hydroxide $Al(OH)_3$ is 1/3 its molecular weight, etc.

The equivalent weight of an acid is the acid molecular weight divided by its basicity. For example, the equivalent weight of H_2SO_4 is 49 (98 : 2 = 49).

The equivalent weight of a salt is found by dividing its molecular weight by the total number of valence units of the metal (or the total number of valence units of the acid radical) in the salt molecule. For example, the equivalent weight of aluminium sulphate is 57 because the molecular weight of $Al_2(SO_4)_3$ is 342, the valence of aluminium is 3, and the total number of valence units of aluminium is 6 (342 : 6 = 57).

PROBLEMS

5.76. Determine the equivalent weight of iron in its oxide containing 30 per cent of oxygen.

5.77. On burning 1.19 g of a metal, 1.51 g of its oxide were formed. Calculate the equivalent weight of the metal.

5.78. 0.18 g of a metal combined with 84 cc of oxygen measured at NTP. What is the equivalent weight of the metal?

5.79. Determine the equivalent weight of a metal 6 g of which displace 0.5 g of hydrogen from acids.

5.80. What quantity of a metal the equivalent weight of which is 29.36 will displace 105 ml of hydrogen (at NTP) from acids?

5.81. Determine the equivalent weights of the following bases: (a) cuprous hydroxide CuOH and cupric hydroxide $Cu(OH)_2$; (b) ferrous hydroxide $Fe(OH)_2$ and ferric hydroxide $Fe(OH)_3$.

5.82. What are the equivalent weights of (a) sulphurous acid H_2SO_3 and phosphoric acid H_3PO_4; (b) nitrous acid HNO_2 and carbonic acid H_2CO_3?

5.83. Calculate the equivalent weights of the following salts: (a) $Al(NO_3)_3$ and $Fe_2(SO_4)_3$; (b) K_2SO_4 and $Ca_3(PO_4)_2$; (c) Na_3PO_4 and $FeCl_2$; (d) K_2CO_3 and $Ba(NO_3)_2$.

23. Normality of Solutions

Normal concentration (or simply normality) of solution is the number of gram-equivalents of solute contained in one litre of solution.

A solution containing one gram-equivalent of solute per litre is called normal, a solution containing 0.1 gram-equivalent of solute per litre is a decinormal solution, etc.

The normality is designated by the letter *N* preceded by the coefficient. For example, a solution containing two gram-equivalents of solute per litre is designated 2 *N*, that containing 0.01 gram-equivalent of solute per litre, 0.01 *N*, etc.*

The normality of a solution can be determined by dividing the number of grams of solute contained in one litre of solution by the gram-equivalent of the solute.

Determining quantity of solute and water required to prepare a given quantity of solution of wanted normality.

Example 1. What quantities in grams of sodium chloride NaCl and water are required to prepare 0.5 litre of a 2 *N* solution?

Solution: The molecular weight of NaCl is 23 + 35.5 = = 58.5, and the gram-molecular weight is 58.5 g.

$$1 \text{ g-equiv} = \frac{\text{mole}}{1} = 58.5 \text{ g}$$

(1) 1 litre of a 1 *N* solution contains 58.5 g
1 litre of a 2 *N* solution contains 58.5 × 2=117 g

(2) 1 litre of a 2 *N* solution contains 117 g
0.5 litre of a 2*N* solution contains x g

$$x = 117 \times 0.5 = 58.5 \text{ g}$$

(3) 500 — 58.5 = 441.5 g of water.

Answer: To prepare 0.5 litre of a 2 *N* solution of sodium chloride, 58.5 g of NaCl should be dissolved in 441.5 ml of water.

Determining normality of solution from a given quantity of solute and the known volume of solution.

Example 2. Determine the normality of a solution of sulphuric acid 250 ml of which contain 24.5 g of H_2SO_4.

Solution: (1) 250 ml of H_2SO_4 solution contain 24.5 g of H_2SO_4
1,000 ml of H_2SO_4 solution contain x g of H_2SO_4.

Solving by the proportion method:

$$250 : 1{,}000 = 24.5 : x$$

whence

$$x = \frac{24.5 \times 1{,}000}{250} = 98 \text{ g}$$

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* Another way of designating fractional normality of solutions is by common fractions, e.g. *N*/10 (0.1 *N*), *N*/20, (0.05 *N*), etc.—*Tr*,

(2) The molecular weight of H_2SO_4 is 98, and its one mole weighs 98 g.

$$1 \text{ g-equiv} = \frac{\text{mole}}{2} = \frac{98}{2} = 49 \text{ g}$$

(3) 49 g are contained in 1 litre of a 1 N solution
98 g are contained in x litres of a 1 N solution.
Solving by the proportion method:

$$49 : 98 = 1 : x$$

whence

$$x = \frac{98}{49} = 2$$

Answer: The normality of the given solution of sulphuric acid is 2.

Normality is a convenient way of expressing concentration of reacting solutions. This is so because solutions of the same normality interact by equal volumes since they contain equivalent quantities of the reacting substances.

If solutions of different normalities are used their volumes are inversely proportional to their normalities.

If we denote the normalities of two reacting solutions by N_1 and N_2, and their volumes by V_1 and V_2 respectively, the above relationship can be expressed by the following proportion:

$$V_1 : V_2 = N_2 : N_1$$

or

$$V_1N_1 = V_2N_2$$

Making use of this formula one can easily calculate the volumes of solutions required to accomplish the wanted reaction.

Example 3. What volume of a normal solution of hydrochloric acid is required to neutralize potassium hydroxide contained in 10 ml of a 0.2 N solution?

Solution: If we designate the sought volume of the solution of hydrochloric acid by V_1, then

$$V_1 \cdot 1 = 10 \times 0.2,$$

whence

$$V_1 = \frac{1 \times 10}{0.2} = 50$$

Answer: 50 ml of a normal solution of hydrochloric acid.

Example 4. Determine the normality of a solution of sulphuric acid 15 ml of which react without residue with 30 ml of a 0.5 N solution of barium chloride.

Solution: Designating the normality of the solution of sulphuric acid by N, we have

$$15N_{H_2SO_4}=30\times 0.5$$

whence

$$N_{H_2SO_4}=\frac{30\times 0.5}{15}=1.0$$

Answer: The normality of the sulphuric acid is 1.

Determining titre of solution from its normality and the normality of solution from its titre.

The titre of a solution T is the quantity of solute in grams contained in 1 ml of solution. The titre is calculated from the formula

$$T=\frac{NE}{1,000}$$

For example, the titre of a 1 N solution of H_2SO_4 is

$$T_{H_2SO_4}=\frac{1\times 49]}{1,000}=0.049$$

and the titre of a 0.1 N solution of NaOH is

$$T_{NaOH}=\frac{0.1\times 40}{1,000}=0.004, \text{ etc.}$$

Knowing the titre of a solution, one can easily calculate its normality:

$$N=\frac{T\times 1,000}{E}$$

For example, if the titre of a solution of NaOH is 0.004, its normality is

$$N=\frac{0.004\times 1,000}{40}=0.1$$

PROBLEMS

5.84. What quantity in grams of potassium hydroxide KOH is contained in one litre of a solution the normality of which is (a) 1; (b) 0.25; (c) 0.5; (d) 2.5; (e) 10; (f) 0.02?

5.85. What quantity in grams of sulphuric acid H_2SO_4 is contained in 0.5 litre of a solution the normality of which is (a) 1; (b) 1.25; (c) 0.5; (d) 0.2; (e) 4; (f) 0.06?

5.86. What quantity in grams of phosphoric acid H_3PO_4 is contained in 2 litres of a solution the normality of which is (a) 1; (b) 0.5; (c) 0.75; (d) 0.02; (e) 4; (f) 10?

5.87. What is the normality of a solution containing (a) 12.6 g of HNO_3 in 2 litres; (b) 0.49 g of H_2SO_4 in 1 litre; (c) 29.75 g of NaCl in 0.5 litre; (d) 0.8 g of NaOH in 200 ml?

5.88. Calculate the volume of a 0.1 *N* solution of sulphuric acid required to neutralize completely sodium hydroxide contained in 25 ml of its 0.2 *N* solution.

5.89. What is the normality of a solution of sodium hydroxide 15 ml of which neutralize 30 ml of a 0.5 *N* solution of hydrochloric acid?

5.90. Determine the normality of a solution of phosphoric acid 20 ml of which neutralize 10 ml of a normal solution of potassium hydroxide.

5.91. What volume of a 0.1 *N* solution of sodium hydroxide is required to neutralize (a) 10 ml of a 0.1 *N* solution of hydrochloric acid; (b) 20 ml of a 0.2 *N* solution of hydrochloric acid; (c) 5 ml of a 1 *N* solution of phosphoric acid?

5.92. Calculate the normality of a solution of nitric acid HNO_3 knowing that 15 ml of a 0.5 *N* solution of potassium hydroxide KOH neutralize 30 ml of the acid.

5.93. Calculate the titre of a 0.1 *N* solution of (a) NaOH; (b) KOH; (c) HCl; (d) H_2SO_4; (e) $Al(NO_3)_3$.

5.94. Determine the normality of a solution of NaOH the titre of which is (a) 0.08; (b) 0.12; (c) 0.16.

24. Electrolytic Dissociation. Electrolysis

In making out ionic equations of reactions one should bear in mind that the ionic equation is one in which the reacting ions and molecules, and also the products of their interaction are only designated.

Example 1.

The equation in the molecular form:

$$AgNO_3 + NaCl = \downarrow AgCl + NaNO_3$$

The same equation in the ionic form:

$$Ag^+ + NO_3^- + Na^+ + Cl^- = \downarrow AgCl + Na^+ + NO_3^-$$

The concise ionic equation:

$$Ag^+ + Cl^- = AgCl$$

Example 2.

$$CuO + H_2SO_4 = CuSO_4 + H_2O$$

$$CuO + 2H^+ + SO_4^{2-} = Cu^{2+} + SO_4^{2-} + H_2O$$

$$CuO + 2H^+ = Cu^{2+} + H_2O$$

PROBLEMS

5.95. Indicate which of the following substances are conductors of electricity: river water, benzene, molten sodium hydroxide, aqueous solution of potassium chloride, dry table salt, alcohol, distilled water.

5.96. Indicate which of the following substances are electrolytes: potassium hydroxide, water, sugar, table salt, nitric acid, alcohol.

5.97. Why (and how) does hydrochloric acid react with zinc and many other metals, while anhydrous liquefied hydrogen chloride does not?

5.98. Why does an aqueous solution of sodium chloride NaCl (as well as the solution of this salt in ammonia) conduct electricity? Molten NaCl is also a conductor of electric current. However, dry table salt and its solution in some other liquids do not conduct electricity. Explain this phenomenon.

5.99. What ions are present in aqueous solutions of (a) barium chloride $BaCl_2$; (b) zinc sulphate $ZnSO_4$; (c) sodium hydroxide $NaOH$; (d) phosphoric acid H_3PO_4; (e) metaphosphoric acid HPO_3?

5.100. Make out the formulas of electrolytes the aqueous solutions of which contain the following ions (in pairs): (a) Rb^+ and OH^-; (b) Ca^{2+} and Br^-; (c) H^+ and NO_3^-; (d) Fe^{3+} and SO_4^{2-}; (e) K^+ and HCO_3^-; (f) Na^+ and CO_3^{2-}; (g) $MgOH^+$ and OH^-.

5.101. Derive formulas of substances the aqueous solutions of which contain the following ions: (a) I^-; (b) SO_4^{2-}; (c) Cl^-; (d) Br^-; (e) CO_3^{2-}; (f) HCO_3^-; (g) HSO_4^-; (h) PO_4^{3-}; and (i) F^-.

5.102. Aqueous solutions of what electrolytes contain hydrogen ions: (a) KOH; (b) H_2SO_4; (c) $Ba(OH)_2$; (d) $NaHSO_4$; (e) $HMnO_4$?

5.103. What reagents can identify the following ions in solution: (a) H^+; (b) OH^-; (c) Cl^-; (d) SO_4^{2-}; (e) Ba^{2+}; (f) Ag^+?

5.104. Indicate substances aqueous solutions of which contain S^{2-} ions: (a) potassium sulphate K_2SO_4; (b) sodium sulphide Na_2S; (c) potassium sulphite K_2SO_3; (d) sodium thiosulphate $Na_2S_2O_3$ (hypo); (e) potassium hydrosulphide KHS; (f) hydrogen sulphide H_2S.

5.105. Which of the following electrolytes contain in their aqueous solutions chloride ion Cl^-: (a) aluminium chloride $AlCl_3$; (b) sodium perchlorate $NaClO_4$; (c) potassium hypochlorite KOCl; (d) potassium chlorate $KClO_3$; (e) barium chloride $BaCl_2$?

5.106. Derive equations of electrolytic dissociation of (a) hydroiodic acid HI; (b) sulphurous acid H_2SO_3; (c) boric H_3BO_3; (d) selenic H_2SeO_4; (e) antimonic H_3SbO_4. How many gram-ions* of hydrogen are formed in dissociation of one mole of each of the above-named acids? The first dissociation of H_2SO_3, H_3BO_3, H_2SeO_4, H_3SbO_4 should only be counted.

5.107. Write down the equations of stepped dissociation of carbonic acid H_2CO_3 and phosphoric acid H_3PO_4.

How many gram-ions of $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-} are formed in the stepped dissociation of a gram-molecule of H_3PO_4?

5.108. Write down the equations of electrolytic dissociation of the following bases: (a) CsOH; (b) $Ba(OH)_2$; (c) $Al(OH)_3$. How many gram-ions of metal and hydroxyl are formed during dissociation of a gram-molecule of each of the above-named bases?

5.109. Write down the equations of stepped dissociation of the bases $Ca(OH)_2$ and $Fe(OH)_3$. How many gram-ions of (a) $CaOH^+$; (b) $Fe(OH)_2^+$; and (c) $FeOH^{2+}$ are formed during dissociation of a gram-molecule of the corresponding base?

5.110. How do amphoteric hydroxides like zinc hydroxide $Zn(OH)_2$ dissociate in water?

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* A gram-ion is a quantity of an ion in grams numerically equal to the sum of the atomic weights of the elements in the given ion.

5.111. Derive the equations for dissociation of amphoteric hydroxide $Al(OH)_3$ as an acid and as a base. How many gram-ions of Al^{3+} and AlO_2^- are formed during dissociation of one gram-molecule of aluminium hydroxide?

5.112. Write down the equations of electrolytic dissociation of the following salts: (a) $BaCl_2$; (b) Na_2CO_3; (c) $Fe_2(SO_4)_3$; (d) $Al(NO_3)_3$; (e) $Zn(NO_3)_2$; (f) $NaNO_3$; (g) $AlCl_3$; and (h) K_3PO_4.

Calculate the quantities in gram-ions of the metal and the acid radical obtained as a result of complete dissociation of 0.1 mole of each salt.

5.113. How many gram-molecules of the following nitrates contain equal quantities of NO_3^- ion: (a) KNO_3; (b) $Ca(NO_3)_2$; (c) $Al(NO_3)_3$?

5.114. What quantity in grams of each of the following bases contains equal quantities of gram-ion of hydroxyl: (a) LiOH; (b) $Ca(OH)_2$; (c) $Al(OH)_3$?

5.115. What quantities of the acids given below contain 0.5 g-ion of hydrogen: (a) HCl; (b) HNO_3; (c) H_2SO_4?

5.116. Which solution of sulphuric acid contains greater quantity of the hydrogen ion, a 10 or a 2 per cent solution?

5.117. Determine the quantities of magnesium chloride and magnesium nitrate containing equal quantities of gram-ions of magnesium.

5.118. What quantities in grams of (a) sodium sulphate; (b) zinc sulphate; (c) aluminium sulphate contain equal quantities of gram-ion of SO_4^{2-}?

5.119. What quantities in grams of a 10 per cent solution of sodium hydroxide and potassium hydroxide will precipitate equal quantities of gram-ions of Cu^{2+} by acting on 20 g of a 5 per cent solution of $CuSO_4$?

5.120. What is the degree of dissociation of an electrolyte if (a) 40 out of each 100 molecules dissociate into ions; (b) 12 of each 20 molecules are dissociated?

5.121. The degree of dissociation of an electrolyte is 0.3. How many molecules out of each ten molecules of solute dissociate?

5.122. Derive molecular and ionic equations for the interaction of the following substances:

(a) potassium chloride and sulphuric acid;

(b) aluminium chloride and sulphuric acid;

(c) sodium nitrate and sulphuric acid;
(d) aluminium nitrate and sulphuric acid;
(e) silver nitrate and aluminium chloride;
(f) copper sulphate and sodium hydroxide;
(g) ferric chloride and potassium hydroxide;
(h) sodium hydroxide and phosphoric acid.

5.123. Write down the molecular and ionic equations for the interaction between the following substances:

(a) $BaCl_2 + K_2SO_4 \rightarrow$ (c) $Ba(NO_3)_2 + Na_2SO_4 \rightarrow$
(b) $BaCl_2 + Fe_2(SO_4)_3 \rightarrow$ (d) $BaI_2 + Na_2SO_4 \rightarrow$

5.124. Write down the ionic equations for the following exchange reactions:

(a) $AgNO_3 + NaCl \rightarrow$ (b) $AgNO_3 + AlCl_3 \rightarrow$

5.125. What concise ionic equations can describe the essence of the following reactions?

(a) $FeCl_2 + KOH \rightarrow$ (b) $Fe(NO_3)_2 + Ca(OH)_2 \rightarrow$

5.126. Write down the ionic equations for the following reactions:

(a) $CuSO_4 + KOH \rightarrow$ (c) $Cu(NO_3)_2 + KOH \rightarrow$
(b) $CuSO_4 + NaOH \rightarrow$ (d) $CuCl_2 + Ca(OH)_2 \rightarrow$

5.127. Write down the ionic equations for the following reactions:

(a) $NaOH + HCl \rightarrow$ (c) $Cu(OH)_2 + HNO_3 \rightarrow$
(b) $KOH + H_2SO_4 \rightarrow$ (d) $NaOH + H_3PO_4 \rightarrow$

5.128. Write down the ionic equations for the following reactions:

(a) $MgCl_2 + KOH \rightarrow$ (c) $MgCl_2 + Ca(OH)_2 \rightarrow$
(b) $Mg(NO_3)_2 + KOH \rightarrow$ (d) $MgSO_4 + NaOH \rightarrow$

5.129. Write down the ionic equations for the following reactions:

(a) $FeCl_3 + Ca(OH)_2 \rightarrow$ (c) $Fe_2(SO_4)_3 + NaOH \rightarrow$
(b) $Fe(NO_3)_3 + Ba(OH)_2 \rightarrow$ (d) $FeCl_3 + KOH \rightarrow$

5.130. Write down the ionic equations for the following reactions bearing in mind that $Al(OH)_3$ is produced in them:

(a) $Al(NO_3)_3+KOH \rightarrow$ (c) $Al_2(SO_4)_3+NaOH \rightarrow$

(b) $AlCl_3+Ca(OH)_2 \rightarrow$ (d) $Al(NO_3)_3+Ca(OH)_2 \rightarrow$

5.131. Write down the equations for the reactions that take place at the electrodes during electrolysis of (a) water; (b) hydrochloric acid; (c) sulphuric acid.

5.132. What is formed at the cathode (or in the cathode space) and also at the anode (or in the anode space) during electrolysis of (a) molten sodium chloride (platinum electrodes); (b) aqueous solution of table salt (carbon electrodes); (c) water slightly acidified with sulphuric acid; (d) solution of copper chloride (carbon electrodes); (e) solution of copper sulphate (copper electrodes)?

25. Laboratory Exercises

5.133. Detect the presence in the test solution of the ions: (a) H^+; (b) OH^-; (c) Cl^-; (d) SO_4^{2-}; (e) Ag^+; (f) Ba^{2+}; (g) Fe^{2+}; (h) Fe^{3+}.

5.134. Accomplish reactions described by the following ionic equations:

(a) $2H^++S^{2-}=H_2S$ (d) $Ag^++Cl^-=AgCl$

(b) $2H^++SiO_3^{2-}=H_2SiO_3$ (e) $Cu^{2+}+2OH^-=Cu(OH)_2$

(c) $Fe^{2+}+2OH^-=Fe(OH)_2$ (f) $Ba^{2+}+SO_4^{2-}=BaSO_4$

5.135. A solution of potassium iodide is available. Accomplish the transition

$$2I^- \rightarrow I_2$$

5.136. Establish experimentally, which solutions contain the ions: (a) S^{2-}; (b) SO_3^{2-}; (c) SO_4^{2-}.

26. Oxidation-Reduction Reactions

Oxidation-reduction reactions are characterized by the changing valence of the elements in molecules of the reacting substances. This is explained by the transfer of electrons from molecules (ions or atoms) of the reducing agent to molecules (ions or atoms) of the oxidizing agent. The number of electrons lost by the reducing agent in the oxidation-reduction reaction is equal to the number of electrons gained by the oxidizer.

Example 1. Make out the equation of the reaction between hydrogen sulphide H_2S and bromine Br_2.

(1) The scheme of the reaction is as this:

$$H_2S + Br_2 \rightarrow HBr + S$$

(2) Determine which of the elements change their valence and put the appropriate figure (with the plus or minus sign) over the symbols in both parts of the scheme*:

$$H_2\overset{-2}{S} + Br_2^0 \rightarrow H\overset{-1}{Br} + S^0$$

The above diagram shows that the valence of sulphur has increased from —2 to 0, while the valence of bromine decreased from 0 to —1. Hence, hydrogen sulphide is a reductant since its sulphur atom S^{2-} loses two electrons, and bromine Br_2 is the oxidant, since the bromine atoms of its molecule gain one electron each.

(3) Now write down the electronic equations describing the processes of oxidation and reduction:

$$S^{2-} - 2e \rightarrow S^0 \text{ (oxidation)}$$

$$Br^0 + e \rightarrow Br^- \text{ (reduction)}$$

(4) Determine the coefficients for the reductant and the oxidant, and hence for the reaction products, by finding the least multiple for the valences. Take into account that the number of electrons lost by the reductant should always be equal to the number of electrons gained by the oxidant:

$$\begin{array}{r|l} 1 & S^{2-} - 2e \rightarrow S^0 \\ 2 & Br^0 + e \rightarrow Br^- \end{array}$$

Figures 1 and 2 placed on the left of the vertical line are the coefficients at the reductant and the oxidant in the reaction equation.

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* In this textbook, the minus or plus sign is placed before the figure to designate the valence (above the chemical symbol), as in $H_2\overset{-2}{S}$, and after the figure to denote the charge on the ion, as in S^{2-}.

The coefficients in this particular reaction indicate that one S^{2-} ion is oxidized by two bromine atoms (the bromine molecule Br_2) and one neutral atom of sulphur S^0 is formed together with two bromine ions $2Br^-$.

Since the coefficients are known, the reaction can now be expressed by the equation:

$$H_2S + Br_2 = 2HBr + S$$

or in the ionic form:

$$S^{2-} + Br_2^0 = 2Br^- + S^0$$

Example 2. Derive the equation for the reaction between hydrogen iodide and concentrated sulphuric acid.

(1) The scheme of the reaction is

$$HI + H_2SO_4 \rightarrow I_2 + H_2S$$

(2) Determine the valence of the elements participating in the oxidation-reduction reaction, before and after the reaction, and put the appropriate designations above the corresponding symbols:

$$H\overset{-1}{I} + H_2\overset{+6}{S}O_4 \rightarrow I_2^0 + H_2\overset{-2}{S}$$

The scheme shows that iodine has been oxidized in the reaction and its ions lost one electron each, whereas sulphur has been reduced owing to the electron transfer from iodine to sulphuric acid. HI is the reductant and H_2SO_4 is the oxidant. Now describe the processes that take place in this reaction by means of electronic equations:

$$\begin{array}{r|l} 8 & I^- - e = I^0 \text{ (oxidation)} \\ 1 & \overset{+6}{S} + 8e = S^{2-} \text{ (reduction)} \end{array}$$

Since the number of electrons lost by the iodide ions should be equal to the number of electrons gained by the sulphur atoms in the molecules of sulphuric acid, it is quite evident that each sulphur atom reacts with eight iodide ions, that is one molecule of the acid H_2SO_4 reacts with eight molecules of HI. Hence, the coefficients for the reductant and the oxidant are 8 and 1.

It is quite evident also that eight HI molecules will produce four molecules of I_2, and one molecule of sulphuric acid will produce only one molecule of H_2S. Place the found coefficients into the scheme:

$$8HI + H_2SO_4 \rightarrow 4I_2 + H_2S$$

By comparing the numbers of hydrogen atoms in both parts of the scheme one can see that eight hydrogen atoms are missing in the right-hand part of it. Hence, in addition to the direct products of the reaction of oxidation-reduction, water is also produced. Determine the number of molecules of water from the number of missing hydrogen atoms. If we add now four molecules of water to the right-hand part of the above scheme we have an equilibrated equation of the reaction:

$$8HI + H_2SO_4 = 4I_2 + H_2S + 4H_2O$$

The check shows that the number of atoms of oxygen in both parts of the equation is the same, hence the equation is correct.

In addition to the reducing and oxidizing agents, substances which serve as a medium for the reactants also take part in the oxidation-reduction reactions. These are acids and alkalis (in addition to water). In reactions where these substances take part, after determining the coefficients for the oxidant and the reductant, and also the products of their interaction, the coefficients should also be found for the other substances participating in the reaction.

Example 3. Derive the equation for the reaction between ferrous sulphate and potassium chlorate in sulphuric acid medium.

(1) The scheme of the reaction is

$$FeSO_4 + KClO_3 + H_2SO_4 \rightarrow Fe_2(SO_4)_3 + KCl + H_2O$$

(2) Considering the valence of the elements, determine the oxidant and the reductant:

$$\overset{+2}{Fe}SO_4 + K\overset{+5}{Cl}O_3 + H_2SO_4 \rightarrow \overset{+3}{Fe_2}(SO_4)_3 + K\overset{-1}{Cl} + H_2O$$

The reductant is $FeSO_4$ and the oxidant, $KClO_3$.

(3) The electronic equations of the oxidation-reduction process are:

$$Fe^{2+} - e \rightarrow Fe^{3+} \text{ (oxidation)}$$

$$\overset{+5}{Cl} + 6e \rightarrow Cl^- \text{ (reduction)}$$

(4) Determine the coefficients:

$$\begin{array}{c|l} 6 & \mathrm{Fe^{2+}} - e \longrightarrow \mathrm{Fe^{3+}} \\ 1 & \overset{+5}{\mathrm{Cl}} + 6e \longrightarrow \mathrm{Cl^-} \end{array}$$

Put the found coefficients into the scheme:

$$6FeSO_4 + KClO_3 + H_2SO_4 \longrightarrow 3Fe_2(SO_4)_3 + KCl + H_2O$$

(5) Now equalize the number of acid radicals SO_4

$$6FeSO_4 + KClO_3 + 3H_2SO_4 \longrightarrow 3Fe_2(SO_4)_3 + KCl + H_2O$$

(6) Now we find the number of water molecules and obtain the reaction equation:

$$6FeSO_4 + KClO_3 + 3H_2SO_4 = 3Fe_2(SO_4)_3 + KCl + 3H_2O$$

(7) By checking the number of oxygen atoms in both parts of the equation, one can make sure that the equation is correct.

The ionic equation of the reaction is:

$$6Fe^{2+} + ClO_3^- + 6H^+ = 6Fe^{3+} + Cl^- + 3H_2O$$

Example 4. Derive the equation for the interaction between manganese dioxide and bromine in an alkali medium.

(1) The scheme of the reaction is

$$MnO_2 + Br_2 + KOH \longrightarrow K_2MnO_4 + KBr + H_2O$$

(2) Determine the oxidant and the reductant from the valences of the elements:

$$\overset{+4}{\mathrm{Mn}}\mathrm{O_2} + \mathrm{Br_2^0} + \mathrm{KOH} \longrightarrow \mathrm{K_2}\overset{+6}{\mathrm{Mn}}\mathrm{O_4} + \mathrm{K}\overset{-1}{\mathrm{Br}} + \mathrm{H_2O}$$

The reductant is MnO_2 and the oxidant is Br_2.

(3) Write down the electronic equations for the oxidation-reduction process:

$$\overset{+4}{\mathrm{Mn}} - 2e \longrightarrow \overset{+6}{\mathrm{Mn}} \text{ (oxidation)}$$

$$\mathrm{Br^0} + e \longrightarrow \mathrm{Br^-} \text{ (reduction)}$$

(4) Determine the coefficients for the oxidant and the reductant:

$$\begin{array}{c|l} 1 & \overset{+4}{\mathrm{Mn}} - 2e \longrightarrow \overset{+6}{\mathrm{Mn}} \\ 2 & \mathrm{Br^0} + e \longrightarrow \mathrm{Br^-} \end{array}$$

$$MnO_2 + Br_2 + KOH \longrightarrow K_2MnO_4 + 2KBr + H_2O$$

(5) There are four potassium ions in the right-hand and one in the left-hand part of the scheme, therefore the coefficient 4 is placed before KOH in the left-hand part of the scheme:

$$MnO_2+Br_2+4KOH = K_2MnO_4+2KBr+H_2O$$

(6) Equalize now the number of hydrogen atoms in the equation:

$$MnO_2+Br_2+4KOH = K_2MnO_4+2KBr+2H_2O$$

(7) The equation can be checked by comparing the number of oxygen atoms in both parts. The ionic equation of the reaction is

$$MnO_2+Br_2^0+4OH^-=MnO_4^{2-}+2Br^-+2H_2O$$

If neither acid nor alkali is added to the starting substances, the oxidationreduction process is assumed to proceed in a neutral medium. In such cases water should also be put into the left-hand part of the equation (if necessary).

Example 5. Derive the equation of the oxidation-reduction reaction according to this scheme:

$$H_2\overset{+4}{S}O_3+Cl_2^0 \rightarrow H_2\overset{+6}{S}O_4+H\overset{-1}{Cl}$$

The scheme shows that in the reaction the valence of sulphur has increased from +4 to +6, while the valence of chlorine decreased from 0 to —1.

The valence increases due to the transfer of two electrons from the molecule of sulphurous acid towards the chlorine molecule. As a result, the tetravalent sulphur atom (in H_2SO_3) converts into a positively hexavalent sulphur atom (in H_2SO_4). At the same time, chlorine atoms gain one electron each to turn into singly charged negative chloride ions Cl^-.

Express these processes by electronic equations and find the coefficients for the oxidant and the reductant:

$$\begin{array}{r|l}
1 & \overset{+4}{S}-2e \rightarrow \overset{+6}{S} \quad \text{(oxidation)} \\
1 & 2Cl^0+2e \rightarrow 2Cl^- \quad \text{(reduction)}
\end{array}$$

The equations show that one molecule of chlorine Cl_2 is spent to oxidize one molecule of H_2SO_3 to produce one molecule of H_2SO_4 and two molecules of HCl.

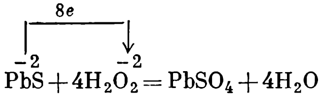
By placing the coefficient 2 at HCl, we have

$$H_2SO_3+Cl_2 \longrightarrow H_2SO_4+2HCl$$

By counting the number of hydrogen atoms in both parts of the scheme one can come to the conclusion that one molecule of water should also take part in the reaction. By putting the missing water molecule into the left-hand part, we can now equilibrate the equation:

$$H_2SO_3+Cl_2+H_2O=H_2SO_4+2HCl$$

Some substances, for example hydrogen peroxide H_2O_2, can act both as the oxidant and the reductant. For example, H_2O_2 acts as the oxidant in the reaction

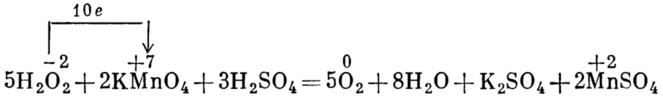


$$\overset{-2}{PbS}+4H_2\overset{-2}{O}_2=PbSO_4+4H_2O$$

Taking up two electrons, the O_2^{2-} ion converts in this reaction into negatively charged oxygen ions:

$$O_2^{2-}+2e=2O^{2-}$$

In other reactions H_2O_2 can also act as the reductant, losing thereby two electrons to form a molecule of oxygen, for example:

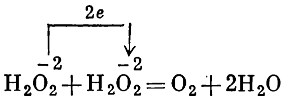


$$5H_2\overset{-2}{O}_2+2K\overset{+7}{Mn}O_4+3H_2SO_4=5\overset{0}{O}_2+8H_2O+K_2SO_4+2\overset{+2}{Mn}SO_4$$

In the reaction

$$2H_2O_2=2H_2O+O_2$$

the oxygen ions in the molecules of H_2O_2 act both as the oxidant and the reductant:



$$H_2\overset{-2}{O}_2+H_2\overset{-2}{O}_2=O_2+2H_2O$$

Such reactions are known as auto-oxidation-reduction reactions.

Example 6.

$$2KClO_3 = 2KCl + 3O_2$$

$$\begin{array}{c|c|l} 2 & 1 & \overset{+5}{Cl} + 6e \longrightarrow Cl^- \text{ (reduction)} \\ 6 & 3 & O^{2-} - 2e \longrightarrow O^0 \text{ (oxidation)} \end{array}$$

This reaction can be referred to the intermolecular oxidation-reduction reactions. $\overset{+5}{Cl}$ acts here as the oxidant and $\overset{-2}{O}$ is the reductant which is oxidized to O_2.

Example 7.

$$2HgO = 2Hg + O_2$$

$$\begin{array}{c|c|l} 2 & 1 & Hg^{2+} + 2e \longrightarrow Hg^0 \\ 2 & 1 & O^{2-} - 2e \longrightarrow O^0 \end{array}$$

Hg^{2+} is the oxidant, and O^{2-} is the reductant.

PROBLEMS

5.137. Indicate in which cases the electrons are gained and in which lost:

(a) $\overset{+2}{N} \longrightarrow \overset{+4}{N}$

(b) $S^{2-} \longrightarrow \overset{+6}{S}$

(c) $\overset{+5}{P} \longrightarrow \overset{+3}{P}$

(d) $\overset{+7}{Mn} \longrightarrow Mn^{2+}$

(e) $Cl^- \longrightarrow \overset{+1}{Cl}$

(f) $P^0 \longrightarrow P^{3-}$

(g) $I^- \longrightarrow I^0$

(h) $Ca^0 \longrightarrow Ca^{2+}$

5.138. Indicate in which cases the oxidation and in which reduction processes take place:

(a) $Zn \longrightarrow ZnSO_4$

(b) $HNO_3 \longrightarrow NO_2$

(c) $P \longrightarrow HPO_3$

(d) $NO \longrightarrow HNO_3$

(e) $Cl_2O \longrightarrow HCl$

(f) $HClO \longrightarrow HCl$

(g) $Cr(OH)_3 \longrightarrow K_2CrO_4$

(h) $H_2S \longrightarrow SO_2$

(i) $KMnO_4 \longrightarrow MnO_2$

(j) $Cr_2(SO_4)_3 \longrightarrow K_2Cr_2O_7$

5.139. Indicate the oxidant and reductant elements in the following reactions:

(a) $NaI + Cl_2 \longrightarrow NaCl + I_2$

(b) $Fe + HCl \longrightarrow FeCl_2 + H_2$

(c) $H_2O_2 + PbS \longrightarrow H_2O + PbSO_4$

(d) $H_2O_2 + KI \longrightarrow I_2 + KOH$

(e) $H_2S + SO_2 \longrightarrow H_2O + S$

(f) $I_2 + H_2O_2 \longrightarrow HIO_3 + H_2O$

(g) $Al+H_2SO_4 \rightarrow$
$\rightarrow Al_2(SO_4)_3+H_2$

(h) $CaH_2+H_2O \rightarrow$
$\rightarrow Ca(OH)_2+H_2$

(i) $HCl+HNO_3 \rightarrow$
$\rightarrow Cl_2+NO+H_2O$

5.140. Derive equations of the oxidation-reduction reactions according to the following schemes:

(a) $KI+Br_2 \rightarrow KBr+I_2$
(b) $Al+CuCl_2 \rightarrow AlCl_3+Cu$
(c) $HBr+H_2SO_4 \rightarrow Br_2+SO_2+H_2O$

5.141. Which of the equations given below express oxidation-reduction processes?

(a) $2FeCl_2+Cl_2=2FeCl_3$
(b) $H_2S+Br_2=2HBr+S$
(c) $2KI+Cl_2=2KCl+I_2$
(d) $2NaCl+H_2SO_4=Na_2SO_4+2HCl$
(e) $CaF_2+H_2SO_4=CaSO_4+2HF$

Indicate the oxidant and the reductant.

5.142. Which of the equations given below express the oxidation-reduction processes?

(a) $2HBr+H_2SO_4=Br_2+SO_2+2H_2O$
(b) $4NH_3+3O_2=6H_2O+2N_2$
(c) $K_2CO_3+SiO_2=K_2SiO_3+CO_2$
(d) $SiO_2+4HF=SiF_4+2H_2O$
(e) $Cl_2+H_2O=HClO+HCl$

Indicate the oxidant and the reductant.

5.143. Which of the equations given below express the oxidation-reduction reaction?

(a) $8HI+H_2SO_4=4I_2+H_2S+4H_2O$
(b) $2NaOH+CO_2=Na_2CO_3+H_2O$
(c) $CuSO_4+2KOH=\downarrow Cu(OH)_2+K_2SO_4$
(d) $Mg_3N_2+6H_2O=3Mg(OH)_2+2NH_3\uparrow$
(e) $BaCl_2+K_2CO_3=BaCO_3+2KCl$
(f) $SiO_2+2C=Si+2CO$

Indicate the oxidant and the reductant.

5.144. Write down the equations for the oxidation-reduction processes described schematically below:

(a) $S+HNO_3 \rightarrow H_2SO_4+NO_2+H_2O$

(b) $P+HNO_3+H_2O \rightarrow H_3PO_4+NO$

(c) $H_2S+HNO_3 \rightarrow S+NO_2+H_2O$

(d) $H_2S+HOCl \rightarrow S+HCl+H_2O$

5.145. Write down the equations of the oxidation-reduction reactions described schematically below:

(a) $KBr+MnO_2+H_2SO_4 \rightarrow Br_2+MnSO_4+K_2SO_4+H_2O$

(b) $KCl+KMnO_4+H_2SO_4 \rightarrow Cl_2+MnSO_4+K_2SO_4+H_2O$

(c) $FeCl_3+KI+H_2O \rightarrow FeCl_2+HCl+I_2$

(d) $Zn+HNO_3+H_2SO_4 \rightarrow N_2O+ZnSO_4+H_2O$

CHAPTER SIX

OXYGEN. SULPHUR AND ITS COMPOUNDS

27. Ozone. Hydrogen Peroxide

6.1. What quantity (a) in grams; (b) in gram-molecules; (c) in litres at NTP of ozone can be formed from 4 moles of oxygen?

6.2. What quantity in litres at NTP of ozone can be obtained from (a) 48 g; (b) 2.5 moles; (c) 6.72 litres at NTP of oxygen?

6.3. What is the mass at NTP of (a) 1 litre of ozone; (b) 1 cubic metre of ozone?

6.4. Calculate the density of ozone with respect to (a) hydrogen; (b) air.

6.5. What is the volume of (a) 1 g; (b) 1 kg; (c) 0.25 mole; (d) 0.1 mole of ozone (at NTP)?

6.6. What quantity in grams of sulphuric acid is required to react with a slight excess of barium peroxide BaO_2 to obtain hydrogen peroxide in amounts of (a) 68 g; (b) 3 moles?

6.7. What quantity in grams of barium peroxide BaO_2 will react with sufficient quantity of sulphuric acid to form hydrogen peroxide in the quantities of (a) 13.6 g; (b) 0.5 mole?

6.8. What quantity of hydrogen peroxide can be prepared by acting with 338 g of barium peroxide on sufficient quantity of sulphuric acid?

6.9. What quantity of hydrogen peroxide is formed in the reaction between 49 g of H_2SO_4 and 84.5 g of BaO_2, if the yield is 98 per cent?

6.10. What quantity in grams of hydrogen peroxide must be decomposed to liberate (a) 8 g; (b) 0.1 mole; (c) 2.24 litres (at NTP) of oxygen?

6.11. What quantity in litres of oxygen will be liberated during complete decomposition of (a) 34 g; (b) 3 moles of hydrogen peroxide?

28. Sulphur and Hydrogen Sulphide

6.12. Calculate the percentage content of iron and sulphur in pyrite FeS_2 (assume it containing no admixtures).

6.13. A sample of pyrite contains 42 per cent of sulphur. Calculate the percentage content of pure iron disulphide FeS_2 in the sample.

6.14. How can sulphur be identified in hydrogen sulphide? Describe your experiment and write down the equation of the corresponding reaction.

6.15. What quantity in grams of synthetic hydrogen sulphide can be prepared from (a) 4 moles of hydrogen; (b) 60 g of hydrogen; (c) 10 litres of hydrogen (at NTP); (d) 6.4 g of sulphur; (e) 20 g-atoms of sulphur; (f) 80 kg of sulphur, on condition that sufficient quantity of the other reagent is available?

6.16. What quantity of iron sulphide is required to prepare hydrogen sulphide by reacting it with 20 ml of the following acids: (a) 21.92 per cent hydrochloric acid; (b) hydrochloric acid having the density of 1.12 g/cc; (c) 50.11 per cent sulphuric acid; (d) sulphuric acid having the density of 1.55 g/cc?

6.17. What quantity of hydrogen sulphide in (a) grams; (b) gram-molecules; (c) litres at NTP will be liberated in the reaction between 20 g of calcium sulphite and the required quantity of hydrochloric acid?

6.18. Write down the equations for complete and incomplete combustion of 3.4 g of hydrogen sulphide. Calculate for the former case the quantities of the reaction products expressed in litres (at NTP) and in gram-molecules; and for the latter case in grams.

6.19. What quantity of copper sulphide will be liberated by acting with hydrogen sulphide on 10 g of (a) a 15 per cent, and (b) a 25 per cent solution of copper sulphate?

6.20. Calculate the mass of lead sulphide PbS precipitate formed by the action of hydrogen sulphide on 20 g of a 10 per cent solution of lead nitrate $Pb(NO_3)_2$.

6.21. What is the concentration of a solution of copper chloride $CuCl_2$ if its 300 g react with hydrogen sulphide water to yield (a) 0.2 mole and (b) 12 g of cupric sulphide CuS?

6.22. 80 g of a solution of Na_2SO_4 react with hydrogen sulphide water to give a solution containing 0.1 mole of Na_2S. Calculate the concentration of the starting solution.

6.23. Consult the table of solubility of salts and bases in water* and write down the formulas and the names of sulphides (a) soluble and (b) insoluble in water.

29. Sulphur Dioxide and Sulphurous Acid

6.24. Calculate the quantity in (a) grams; (b) gram-molecules; (c) litres (at NTP) of oxygen required to oxidize 48 g of sulphur into sulphur dioxide.

6.25. What quantity in grams of sulphur is oxidized into sulphur dioxide SO_2 by oxygen taken in amounts of (a) 2 litres (at NTP); (b) 10 g; (c) 0.4 mole?

6.26. What is the volume at NTP of sulphur dioxide liberated during oxidation of (a) 4 g of sulphur; (b) 3 g-atoms of sulphur; (c) 0.5 kg of sulphur?

6.27. What quantity in grams of air is required to oxidize 160 g of sulphur? (Assume the oxygen content of air to be 23 per cent by weight.)

6.28. What quantity of pyrite FeS_2 (assuming it being free of admixtures) is required to produce (a) 358.4 litres (at NTP); (b) 4 moles; (c) 51.2 g of sulphur dioxide?

6.29. What quantity of pyrite containing 80 per cent of iron sulphide FeS_2 produces 5.376 cubic metres of sulphur dioxide on roasting? (Assume the yield of SO_2 being 100 per cent.)

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* See Appendix.

6.30. What quantity of pyrite containing 90 per cent of iron disulphide FeS_2 yields 2 kg of sulphur dioxide on roasting, the yield being 92 per cent?

6.31. What quantity of pyrite containing 44 per cent of sulphur is required to produce 0.5 ton of SO_2, if the loss of the gas during roasting is 2 per cent?

6.32. Sulphur dioxide can be prepared by sintering coal with the mineral anhydrite $CaSO_4$. The resulting products are CaO, SO_2, and CO_2. Write down the equation of the reaction and calculate in per cent the industrial loss of anhydrite if 1.1875 tons of the mineral yield 0.5 ton of SO_2.

6.33. What quantity of SO_2 will be liberated in the reaction between 71 g of sodium sulphite Na_2SO_3 and (a) 49 g of H_2SO_4; (b) 0.5 mole of H_2SO_4; (c) 20 ml of H_2SO_4, density 1.74 g/cc; (d) 10 ml of a 80.24 per cent H_2SO_4?

6.34. What quantity in grams of H_2SO_4 reacts with the required amount of Na_2SO_3 to form (a) 128 g; (b) 6 moles; (c) 1.12 litres (at NTP) of sulphur dioxide?

30. Sulphur Trioxide, Sulphuric Acid and Its Salts

6.35. In what ratio of volumes and masses do oxygen and sulphur dioxide react to form SO_3?

6.36. What quantity in litres (at NTP) of oxygen is required to oxidize 8 moles of sulphur dioxide into sulphuric anhydride?

6.37. 19.2 kg of SO_2 were oxidized by atmospheric oxygen into 22.51 kg of SO_3. Calculate the yield of SO_3 in per cent of theory.

6.38. 0.5 ton of pyrite containing 45 per cent of sulphur was roasted to prepare 440 kg of SO_2. Calculate the yield of SO_2 in per cent of theory.

6.39. 1.6 tons of pyrite containing 40 per cent of sulphur were roasted to prepare 1.248 tons of sulphur dioxide. Calculate the quantity in per cent of sulphur utilized in roasting.

6.40. The production capacity of a kiln for roasting pyrite is 28 tons of the mineral per day, and the yield of sulphur dioxide is 98 per cent of theory. What quantity of SO_2 is produced by the kiln per day if the sulphur content of the pyrite is 42 per cent.

6.41. Calculate the quantity of oxygen required to roast one ton of pyrite containing 45 per cent of sulphur, and also the quantities of (a) sulphur dioxide and (b) iron oxide formed.

6.42. What volume of oxygen reacts with FeS_2 as one ton of pyrite containing 45 per cent of sulphur is roasted? What quantity of (a) Fe_2O_3; (b) SO_2 is formed in this process? Express the quantity of sulphur dioxide in cubic metres (at NTP).

6.43. What quantity of sulphuric acid can be prepared from one ton of iron pyrite containing 45 per cent of sulphur?

6.44. The quantity of sulphuric acid produced by the contact method from 14 tons of pyrite containing 42.4 per cent of sulphur is 18 tons. What is the yield of the acid in per cent of theory?

6.45. The loss of sulphur in preparing sulphuric acid by the contact method is 8 per cent. What quantity of pyrite containing 30 per cent of sulphur is required to prepare one ton of a 96 per cent sulphuric acid?

6.46. How can sulphuric anhydride be prepared from oleum? What quantity of sulphuric anhydride can be prepared from one ton of a 20 per cent oleum?

6.47. What quantity of $BaSO_4$ precipitates on the interaction between (a) 0.5 mole of H_2SO_4 and the theoretically necessary quantity of $BaCl_2$; (b) 0.25 mole of H_2SO_4 and $Ba(NO_3)_2$; (c) 4.9 g of H_2SO_4 and $Ba(OH)_2$?

6.48. 20 ml of 40.35 per cent H_2SO_4 were neutralized by 400 ml of potassium hydroxide solution. Calculate the concentration of the alkali solution.

6.49. The quantity of iron scrap required to produce 2 tons of green vitriol $FeSO_4 \cdot 7H_2O$ containing 52.5 per cent of $FeSO_4$ is 0.5 ton. What is the yield of $FeSO_4$ in per cent of theory?

6.50. One ton of a 98 per cent solution of copper sulphate $CuSO_4$ was produced from 0.48 ton of copper scrap in the manufacture of blue vitriol $CuSO_4 \cdot 5H_2O$. What is the yield of blue vitriol in per cent of theory?

31. Laboratory Exercises

6.51. Prepare sulphur dioxide from sulphuric acid. What quantity of SO_2 can be prepared from 3 moles of sulphuric acid?

6.52. Into an aqueous solution of sulphur dioxide add water slightly coloured with ink. What happens? Boil the solution. Explain the phenomenon observed.

6.53. Wetten a strip of filter paper with a solution of sodium (or potassium) sulphide and dip it into (a) a solution of lead nitrate; (b) a solution of blue vitriol. Explain the phenomena observed.

6.54. Write a few words by a glass rod dipped into a strongly diluted solution of sulphuric acid. Hold the paper over a burner to dry the sheet on both sides. What happens to the inscription? Explain the phenomenon.

6.55. Three test-tubes are filled with three salts of potassium, namely the sulphide, sulphite and sulphate of potassium. By using one reagent (what namely?) identify each salt. Write down the reaction equations and explain them.

6.56. By using a hydrometer, determine the density of a given solution of sulphuric acid. Find in Table 4 (see Appendix) the concentration of the acid and calculate its molar concentration.

6.57. Mix 10 ml of a 48 per cent H_2SO_4 and 100 ml of water. By using a hydrometer, determine the density and the concentration of the prepared solution (consult Table 4 in the Appendix).

6.58. Prepare lead sulphate from lead nitrate. What quantity in grams of the starting salt is required to prepare (a) 4 moles; (b) 20 g of the reaction product?

6.59. Prove experimentally the presence of barium in the crystal hydrate $BaCl_2 \cdot 2H_2O$. Calculate the quantity of water of crystallization contained in 20 g of this crystal hydrate.

32. Review Problems

6.60. What volumes at NTP do (a) 0.1 mole of hydrogen sulphide; (b) 0.2 mole of sulphur dioxide; (c) 3 moles of sulphur trioxide vapour; (d) 0.5 mole of carbon disulphide vapour CS_2 occupy?

6.61. What is the mass at NTP of 2.5 litres of (a) hydrogen sulphide; (b) sulphur dioxide; (c) sulphur trioxide vapour; (d) CS_2 vapour?

6.62. What volume at NTP do (a) 2 g of H_2S; (b) 4 g of SO_2; (c) 6 g of SO_3 vapour; (d) 10 g of CS_2 vapour occupy?

CHAPTER SEVEN

NITROGEN, PHOSPHORUS AND THEIR COMPOUNDS

33. Nitrogen and Its Compounds

7.1. What quantity in grams of ammonium chloride reacts with (a) 28 g of calcium oxide; (b) 5 moles of calcium oxide; (c) 148 g of calcium hydroxide; (d) 8 moles of calcium hydroxide; (e) 684 g of barium hydroxide; (f) 2 moles of barium hydroxide in the process of preparing ammonia?

7.2. What quantity of ammonia can be prepared by reacting 75 kg of commercial slaked lime containing 98.2 per cent of calcium hydroxide with the required quantity of ammonium chloride?

7.3. The production capacity of a column for synthesis of ammonium is 80 tons per day. The column is packed with 3 cubic metres of a catalyst. What quantity of ammonia is synthesized over one cubic metre of the catalyst per hour?

7.4. What reaction can be used tod etect the presence of ammonium ion in an aqueous solution of an ammonium salt? Write down the equation of the reaction and explain it.

7.5. In what volume ratio do gaseous ammonia and hydrogen chloride react to form salt ammoniac? What quantity of salt ammoniac can be prepared from one cubic metre of ammonia at NTP?

7.6. What quantities of ammonium hydroxide and hydrochloric acid are needed to prepare (a) 107 g; (b) 6 moles of ammonium chloride?

7.7. Write down the equation for the reaction of formation of ammonium nitrate from ammonia and nitric acid. Calculate from the equation what quantities of each reagent are required to prepare (a) 40 g; (b) 3 moles of the salt.

7.8. Write down the equation for the reaction of formation of ammonium sulphate from (a) ammonia and sulphuric acid; (b) ammonium hydroxide and sulphuric acid. Calculate the quantities of each reagent required to prepare 264 g of the salt.

7.9. Write down the equation for the reaction of formation of ammonium carbonate from (a) ammonia and carbonic acid; (b) ammonium hydroxide and carbonic acid. From each equation calculate the quantities of the starting substances required for the preparation of (a) 48 g; (b) 2.5 moles of the salt.

7.10. Make out the equation for the reaction of formation of ammonium phosphate from (a) ammonia and phosphoric acid; (b) ammonium hydroxide and phosphoric acid. Calculate the quantities of the reagents required to prepare (a) 298 g; and (b) 6 moles of the salt.

7.11. What quantity of ammonium chloride can be prepared from 35 g of ammonia and 73 g of hydrogen chloride? Which of the two reagents remains in excess?

7.12. What quantity of ammonium chloride can be prepared from 11.2 litres of gaseous ammonia and 11.4 litres of hydrogen chloride at NTP? Which of the starting reagents remains in excess?

7.13. What quantity of ammonium nitrate can be prepared from 52 g of ammonia and 189 g of nitric acid? Which of the two starting reagents remains in excess?

7.14. What quantity of ammonium nitrate can be prepared from 44 litres of gaseous ammonia (at NTP) and 124 g of nitric acid? Will both reagents react completely?

7.15. Ammonium carbonate was prepared from 17 kg of gaseous ammonia and the required quantity of carbonic acid. What is the mass of the reaction product if the yield is 98 per cent?

7.16. What quantity of ammonium carbonate can be liberated by completely decomposing (by heating): (a) 68 g of ammonia; (b) 352 g of carbon dioxide?

7.17. What quantity of synthetic nitrogen oxide can be prepared by reacting (a) 7 g of nitrogen with 8 g of oxygen; (b) 16 g of nitrogen with 16 g of oxygen; (c) 45 litres of nitrogen with 44.8 litres of oxygen at NTP? In which case one of the reagents remains in excess? What is this reagent?

7.18. Nitrogen and oxygen were reacted to prepare nitrogen oxide in the following amounts: (a) 3 moles; (b) 120 g; (c) 4.48 litres (at NTP). What quantity of nitrogen reacted in each case?

7.19. Determine the following specifications of nitrogen oxide: (a) density with respect to air; (b) density with respect to hydrogen; (c) mass of one litre (at NTP); (d) volume of one gram (at NTP); (e) volume of 0.5 mole (at NTP).

7.20. What quantity in grams of nitrogen oxide can be prepared by oxidizing ammonia taken in the quantity of (a) 8 moles; (b) 6.8 kg; (c) 204 g; (d) 44.8 litres at NTP? Calculate for each case the quantity of water formed in the reaction.

7.21. What quantity in grams of nitrogen dioxide can be prepared by oxidizing nitrogen oxide taken in the quantity of (a) 3 moles; (b) 120 g; (c) 4.48 litres at NTP?

7.22. What quantity in grams of nitrogen dioxide can be formed by oxidizing nitrogen oxide taken in the quantity of (a) 184 g; (b) 0.01 kilomole; (c) 2.24 litres at NTP?

7.23. What quantity of oxygen is required to oxidize nitrogen oxide into nitrogen dioxide if (a) 6 g; (b) 3 kilomoles; (c) 7 litres at NTP of nitrogen oxide are available?

7.24. Make out the equation for the reaction of decomposition of concentrated nitric acid with heating. What quantity in grams of nitrogen dioxide is liberated during decomposition of nitric acid taken in amounts of (a) 126 g; (b) 0.25 mole?

7.25. What quantity in grams of concentrated nitric acid is required to prepare (a) 46 g; (b) 6 moles; (c) 9.2 kg; (d) 4.48 litres at NTP of nitrogen dioxide by heating the acid?

7.26. Calculate the quantity of nitric acid that is prepared by reacting 50.5 g of potassium nitrate with the required quantity of sulphuric acid.

7.27. What quantity in grams of sodium nitrate is required to prepare nitric acid in amounts of (a) 3.5 moles; (b) 630 g?

7.28. What quantities in grams of potassium hydrogen sulphate and nitric acid are formed by reacting 20.2 g of potassium nitrate with the required quantity of sulphuric acid?

7.29. What quantity of a 100 per cent nitric acid can be prepared from one ton of ammonia? (Assume the yield of the acid to be 100 per cent and the ammonia containing no admixtures.)

7.30. What quantity of a 100 per cent nitric acid can be prepared from one ton of ammonia, the yield being 92 per cent of theory?

7.31. What quantity of a 100 per cent nitric acid can be prepared by oxidizing 100 cubic metres of ammonia if the yield is 90 per cent?

7.32. What quantity of copper is oxidized on heating it with (a) 56 g of dilute nitric acid; (b) 126 g of concentrated nitric acid? What gas is formed in each case?

7.33. In the reaction between copper hydroxide and nitric acid 47 g of copper nitrate were formed. What quantities of (a) copper hydroxide; and (b) nitric acid were consumed in the reaction?

7.34. Write down the formulas and common names of nitrates used as (a) fertilizers; (b) explosives.

7.35. Lead nitrate $Pb(NO_3)_2$ and copper nitrate $Cu(NO_3)_2$ decompose to form metal oxides, NO_2 and O_2. What quantities of oxygen can be liberated from 0.2 mole of each salt?

7.36. Write down the equation for the reaction of decomposition of potassium nitrate. Name the salt that is formed in the reaction. What quantity in grams of KNO_3 is required to prepare 0.5 mole of this salt?

7.37. Write down the equation for the reaction of decomposition of ammonium nitrite. What quantity of nitrogen is liberated during decomposition of (a) 10 moles; (b) 320 kg of the salt? (The other product of the reaction is water.)

34. Laboratory Exercises

7.38. Prove experimentally that the given substance is an ammonium salt. Write down the equation of the reaction and explain it.

7.39. Heat slightly a small amount of ammonium hydrogen carbonate. Explain the pungent odour of ammonia that appears. Detect the liberated ammonia by an indicator paper. Write down the equation of the reaction and explain it.

7.40. Prove experimentally the presence of nitric oxide in a sealed cylinder. Write down the reaction equation and explain it.

7.41. Prepare sodium nitrate from sodium carbonate. Write down the reaction equation and explain it. What quantity of pure soda is required to prepare 17 kg of sodium nitrate, the yield being 100 per cent.

35. Review Problems

7.42. What quantity of ammonia reacts with 50 kg of sulphuric acid the concentration of which is (a) 92.70 per cent; (b) 90.05 per cent; (c) 83.01 per cent? Assume that a neutral salt is produced in the reaction.

7.43. What quantity of ammonia reacts with 20 kg of nitric acid having the density of (a) 1.430; (b) 1.2; (c) 1.3; (d) 1.19; (e) 1.16; and (f) 1.47 g/cc?

7.44. What quantity of a 50.11 per cent sulphuric acid is required to neutralize 25 kg of an aqueous solution of ammonia having the density of (a) 0.932 and (b) 0.889 g/cc?

7.45. What quantity of an aqueous solution of ammonia having the density of 0.96 g/cc is required to neutralize 200 g of sulphuric acid having the density of (a) 1.040; (b) 1.100; (c) 1.125; (d) 1.170; (e) 1.18; (f) 1.365 g/cc?

7.46. What quantity of a 20.01 per cent hydrochloric acid is required to react with ammonia taken in amounts of (a) 170 g; (b) 2 moles; (c) 4 litres (at NTP)?

7.47. 200 ml of hydrochloric acid having the density of 1.12 g/cc were neutralized with (a) 100 ml; (b) 90 ml of an aqueous solution of ammonia having the density of 0.898 g/cc. What reagent and in what quantity remained unreacted?

7.48. What quantity of ammonium nitrate can be prepared by neutralizing 50 g of a 40 per cent nitric acid with the required quantity of ammonia?

7.49. What quantities of an aqueous solution of ammonia having the density of 0.908 g/cc and water are required to prepare 300 g of a 10 per cent solution of ammonia?

36. Phosphorus and Its Compounds

7.50. White phosphorus is prepared in an electric furnace by heating a mixture of three substances: calcium phosphate, sand and carbon:

$$Ca_3(PO_4)_2 + 3SiO_2 + 5C = 3CaSiO_3 + 2P + 5CO$$

What quantity of calcium phosphate is required to prepare white phosphorus in amounts of (a) 24 kg-atoms; (b) 6.2 tons? The yield of phosphorus should be assumed 100 per cent.

7.51. What quantity of calcium phosphate containing 10 per cent of admixtures is required to prepare phosphorus in the following quantities: (a) 3.1 tons; (b) 155 kg; (c) 62 kg-atoms? The yield of phosphorus should be assumed 100 per cent.

7.52. What quantity of calcium phosphate is required to prepare phosphorus in amounts of (a) 180 kg; (b) 1.55 tons? Assume the yield of phosphorus to be 96 per cent of theory.

7.53. What quantity of calcium phosphate containing 12 per cent of admixtures is required to prepare phosphorus in amounts of (a) 200 kg; (b) 6 tons, if the yield of phosphorus is 92 per cent of theory?

7.54. During production of phosphorus from calcium phosphate carbon monoxide was liberated in the following quantities: (a) 70 kg; (b) 2 m^3 (at NTP); (c) 1.4 tons; (d) 10 kilomoles. What quantity of $Ca_3(PO_4)_2$ was spent in each particular case?

7.55. During production of phosphorus, carbon monoxide was liberated in amounts of (a) 25 kilomoles; (b) 280 kg; (c) 1.5 m^3 (at NTP). Calculate the mass of the starting raw material for each particular case knowing that the purity of calcium phosphate was 96 per cent.

7.56. What quantity of phosphoric anhydride is formed during oxidation of (a) 12.4 g; (b) 8 g-atoms; (c) 62 kg of phosphorus?

7.57. What quantity of phosphorus was oxidized during formation of 7.2 kg of phosphoric anhydride, if the starting material contained 99.5 per cent of pure phosphorus?

7.58. What quantity of phosphoric anhydride combined with water if (a) 0.5 mole; (b) 320 g; (c) 10 kilomoles of metaphosphoric acid were formed?

7.59. 620 kg of natural calcium phosphate (phosphorite) were acted upon with the appropriate quantity of sulphuric acid to prepare 390 kg of phosphoric acid. Calculate the percent content of calcium phosphate $Ca_3(PO_4)_2$ in the starting phosphorite.

7.60. What quantity of gypsum $CaSO_4$ as a side product is produced in the manufacture of phosphoric acid during the interaction of one ton of phosphorite containing 90 per cent of $Ca_3(PO_4)_2$ with sulphuric acid taken in a slightly excessive quantity?

7.61. Write down the molecular and structural formulas of the following phosphates: (a) potassium metaphosphate; (b) calcium metaphosphate; (c) aluminium metaphosphate; (d) potassium orthophosphate; (e) ammonium phosphate, disubstituted; (f) sodium phosphate, monosubstituted; (g) calcium phosphate; (h) ammonium dihydrogen phosphate; (i) calcium hydrogen phosphate. Indicate solubility of the salts in water.

7.62. What is the composition of (a) phosphorite meal; (b) precipitate; (c) superphosphate; (d) double superphosphate; (e) Nitrophoska; (f) Ammo-Phos? Which of these fertilizers is richest in phosphorus?

7.63. What quantity of double superphosphate can be prepared from (a) 0.5 ton; (b) 10 kilomoles; (c) 930 kg of calcium phosphate? Assume the yield of superphosphate to be 100 per cent.

7.64. What quantity of double superphosphate can be prepared from calcium phosphate taken in amounts of (a) 1 ton; (b) 5 kilomoles; (c) 200 kg, if the yield of the finished product is 92 per cent of theory?

7.65. What quantities of calcium phosphate and a 80 per cent phosphoric acid are required to prepare 3 tons of double superphosphate if the yield of the product is 98 per cent of theory?

7.66. 49 kg of phosphoric acid were spent to prepare precipitate $CaHPO_4 \cdot 2H_2O$. What quantity of dry calcium hydroxide containing 2 per cent of admixtures was required for the process?

7.67. Write down the equations for the reactions of formation of (a) monoammonium phosphate; (b) diammonium phosphate; (c) triammonium phosphate from ammonia. Calculate the quantity of ammonium hydroxide which reacts with one gram-molecule of phosphoric acid in each of the above reactions.

7.68. Write the equation for the interaction of monosubstituted calcium phosphate $Ca(H_2PO_4)_2$ with calcium carbonate if disubstituted calcium phosphate $CaHPO_4$, water, and carbon dioxide are formed in the reaction.

7.69. The content of nutrients in phosphate fertilizers would be expressed in weight per cent of phosphoric anhydride P_2O_5. Calculate the percentage content of P_2O_5 in disubstituted calcium phosphate crystal hydrate $CaHPO_4 \cdot 2H_2O$.

7.70. A nutritive solution for fertilizing plants was prepared from 2.5 g of potassium nitrate, 2.5 g of potassium dihydrogen phosphate, and 10 g of calcium nitrate dissolved in one litre of distilled water. Calculate the percentage concentration of each salt in the prepared solution.

CHAPTER EIGHT

CARBON, SILICON AND THEIR COMPOUNDS

37. Carbon and Its Compounds

8.1. What quantity of carbon can reduce completely (a) 16 g; (b) 0.2 mole of copper oxide with formation of carbon dioxide?

8.2. Write down the equation for the reaction of formation of calcium carbide CaC_2 by the action of carbon on calcium oxide. What quantity of calcium oxide is required to prepare one ton of calcium carbide?

8.3. What quantity in (a) grams; (b) gram-molecules; (c) litres at NTP of carbon dioxide is formed during burning in oxygen of 2 gram-atoms of pure carbon?

8.4. What quantity of pure carbon should be oxidized to prepare (a) 4.4 g; (b) 1.25 moles; (c) 112 litres at NTP of carbon dioxide?

8.5. What quantity of carbon dioxide is liberated during roasting limestone taken in amounts of (a) 2 tons; (b) 6 kilomoles? (Admixtures should be disregarded.)

8.6. As marble was calcined 448 litres of CO_2 at NTP were liberated. What quantity of quicklime was formed in this process?

8.7. Chalk containing 96 per cent of calcium carbonate $CaCO_3$ was calcined to prepare 28 tons of lime. What quantity of chalk was loaded into the kiln?

8.8. 1.5 tons of limestone containing 8 per cent of gangue were roasted to liberate 0.6 ton of carbon dioxide. What is the yield of the gas in per cent of theory?

8.9. What quantity of hydrochloric acid reacts with pure calcium carbonate if (a) 2.2 kg; (b) one kilomole; (c) 0.224 m^3 at NTP of carbon dioxide are formed?

8.10. What quantity of calcium carbonate has reacted with hydrochloric acid if 43.2 kg of carbon dioxide were liberated in the process? What substances and in what quantities have been formed in the reaction?

8.11. What quantities of carbon and magnesium oxide are formed in the reaction between 24 g of magnesium and the appropriate quantity of CO_2?

8.12. As magnesium reacted with carbon dioxide 4 g of carbon were formed. What quantity of magnesium took part in the reaction?

8.13. What quantity in grams of calcium hydroxide reacts with the required quantity of carbon dioxide to form calcium carbonate precipitate having the mass of (a) 20 g; (b) 0.25 mole?

8.14. What quantity in litres of CO_2 at NTP reacts with 0.2 mole of $Ca(OH)_2$ to precipitate (a) 0.1 mole and (b) 18 g of calcium carbonate? Does the whole quantity of $Ca(OH)_2$ take part in the reaction? Prove your answer by the appropriate calculations.

8.15. What quantity in grams of water should be reacted with 0.1 mole of carbon dioxide to prepare (a) 0.1 mole; (b) 3.1 g of carbonic acid?

8.16. Calculate from the reaction equation the volume at NTP of CO_2 that can be prepared from 5 kg of limestone containing 94 per cent of $CaCO_3$. What is the percentage content of carbon in this limestone as compared with the theory?

8.17. What quantity in grams of CO_2 can be prepared from 33.6 g of sodium bicarbonate by acting on it with (a) 2.5 moles; (b) 80 g of hydrochloric acid? What substance and in what quantity will remain in excess?

8.18. In the reaction between potassium carbonate and 14 g of a 29.57 per cent hydrochloric acid 2.2 g of carbon dioxide were liberated. What quantity in grams of K_2CO_3 took part in the reaction? Has the whole quantity of hydrochloric acid been spent in the reaction? Prove your answer by the appropriate calculations.

8.19. Solution of potash K_2CO_3 absorbs selectively carbon dioxide from its mixture with other gases to form potassium bicarbonate:

$$K_2CO_3 + H_2O + CO_2 \rightleftarrows 2KHCO_3$$

As the solution is heated to boiling, carbon dioxide is liberated and the absorbing properties of the solution are recovered. This reaction can be utilized for absorbing carbon dioxide from flue and other waste gases. Calculate the quantity of potash required to absorb (a) 220 g of CO_2; (b) 112 litres of CO_2 at NTP; (c) 3 kilomoles of CO_2.

8.20. What quantity of carbon dioxide should be reduced by carbon to prepare (a) 5.6 g; (b) 10 moles; (c) 11.2 litres at NTP of carbon monoxide?

8.21. Calculate the mass and volume of carbon monoxide which should be oxidized to prepare 134.4 litres (at NTP) of carbon dioxide.

8.22. What quantity of phosgene $COCl_2$ is formed in the reaction between (a) 0.1 mole of CO and 0.15 mole of Cl_2; (b) 16 g of CO and 35.5 g of Cl_2; (c) 11.2 litres of CO and 1.2 litres of Cl_2 (at NTP)? What reactant and in what quantity will remain in excess?

8.23. Write down the equation for the reaction of formation of water gas. What quantity of carbon is required to prepare 10 kilomoles of this gas? What quantity of carbon monoxide is formed in this process?

38. Laboratory Exercises

8.24. Prove experimentally that a candle burns to form water and carbon dioxide.

8.25. Prove experimentally that a given vessel is filled with carbonic anhydride. Write down the reaction equation.

8.26. Prepare carbon dioxide by acting with an acid on limestone. Identify the gas by a specific reaction. Calculate from the reaction equation the volume of the gas at NTP that can be prepared from 10 g of limestone containing 90 per cent of $CaCO_3$. What is the percentage content of calcium in this sample of limestone?

8.27. Neutralize sulphuric acid with sodium bicarbonate. Calculate the quantity in grams of sodium bicarbonate required to neutralize 25 ml of sulphuric acid having the concentration of (a) 10.19 per cent; (b) 55.5 per cent.

8.28. Given are solutions of barium chloride, sodium carbonate and sodium sulphite. Identify each solution by using only one (what namely?) reagent. Write down and explain the equations of the appropriate reactions.

8.29. Given are sodium carbonate and sodium sulphate. Identify the salts. Write the equations of the reactions.

8.30. Accomplish the following conversions: barium carbonate → carbon dioxide → barium carbonate. Write down the appropriate reactions.

8.31. Identify chalk, marble, limestone, and graphite in a collection of minerals.

8.32. Prepare 300 g of a 3 per cent solution of sodium bicarbonate.

8.33. 100 g of a 6 per cent solution of sodium carbonate are available. Prepare a 3 per cent solution of soda from the stock solution. Make out the appropriate calculations.

39. Review Problems

8.34. Calculate the mass of 3 litres of (a) carbon monoxide CO; (b) carbon dioxide CO_2; (c) methane CH_4; (d) carbon disulphide vapour CS_2 (at NTP).

8.35. What volume will 20 g of (a) CO; (b) CO_2; (c) CH_4 occupy at NTP?

8.36. Calculate the density with respect to hydrogen and air of (a) CO; (b) CO_2; (c) CH_4.

8.37. What volume will (a) 280 g of carbon monoxide; (b) 84 g of carbon dioxide; (c) 80 g of methane occupy at NTP?

8.38. What quantity in litres (at NTP) of carbon dioxide is formed from 196 g of dry ice?

40. Silicon and Its Compounds

8.39. What quantity of silicon dioxide can be reduced by (a) 4.8 kg; (b) 1.8 g-atoms of carbon?

8.40. What quantity in grams of magnesium reduces 0.25 mole of silicon dioxide? Calculate the masses of the reaction products.

8.41. The salt Na_2SiO_3 was prepared by fusing silica with 10 kg of sodium hydroxide. Calculate the quantity of silica that took part in the reaction and sodium silicate prepared in the reaction.

8.42. Silicon dioxide (59.98 kg) and potassium hydroxide were fused to prepare 77 kg of potassium silicate. What quantity of the alkali took part in the reaction? Which of the reactants was taken in excess?

8.43. What quantities in grams of HCl and Na_2SiO_3 are required to prepare H_2SiO_3 in amounts of (a) 39 g; (b) 1.2 moles?

8.44. Express in per cent by weight the quantity of (a) aluminium oxide; (b) silicon dioxide; (c) water in pure kaolin $Al_2H_4Si_2O_9$ (or $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$).

8.45. Express in per cent by weight the quantity of (a) potassium oxide; (b) alumina; (c) silica in orthoclase $K_2Al_2Si_6O_{16}$ (or $K_2O \cdot Al_2O_3 \cdot 6SiO_2$).

8.46. Derive the equation for the process of chemical erosion of orthoclase. What quantities of (a) kaolin; (b) silica; (c) potash are formed from 135 kg of orthoclase?

8.47. Represent in the form of oxides the following natural silicates: (a) diopside $CaMg[Si_2O_6]$; (b) talcum $Mg_3[Si_2O_5]_2 \cdot [OH]_2$; (c) forsterite $Mg_2[SiO_4]$; (d) nephelite $Na_2[Si_2Al_2O_8]$; (e) anorthite $Ca[Si_2Al_2O_8]$.

8.48. Write down the equations for the reactions illustrating the essence of the process for the production of common silica glass. What quantity of pure silica is required to react with 50 kg of calcium carbonate and 53 kg of sodium carbonate according to stoichiometric calculations?

8.49. Write down the chemical formula of common silica glass. Calculate the percentage content of (a) sodium; (b) calcium; (c) silicon; (d) oxygen in glass.

8.50. The action of hydrofluoric acid on common silica glass is explained by that the acid reacts with silica SiO_2, the component part of glass, as a result of which the volatile compound silicon fluoride SiF_4 is formed:

$$SiO_2 + 4HF = 2H_2O + SiF_4$$

What quantity in grams of silicon dioxide reacts with (a) 0.5 mole; (b) 160 g of hydrofluoric acid?

CHAPTER NINE

METALS

41. Interaction Between Metals and Acids

The action of *sulphuric acid* on metals is different and depends on the concentration of the acid and the nature of a particular metal. Dilute sulphuric acid acts on metals like dilute hydrochloric acid, namely, it dissolves metals standing above lead in the electromotive series. The hydrogen ions of dilute sulphuric acid oxidize metal atoms which give off their electrons. For example, the oxidation of atoms of a bivalent metal (Me) can be expressed by the following scheme:

$$Me = Me^{2+} + 2e^-; \quad 2H^+ + 2e^- = 2H; \quad 2H = H_2$$

The general equation of this reaction for a bivalent metal (a) and a trivalent metal (b) is:

(a) $Me + H_2SO_4 = MeSO_4 + H_2$

(b) $2Me + 3H_2SO_4 = Me_2(SO_4)_3 + 3H_2$

Concentrated sulphuric acid acts on metals in a different way. It oxidizes metals to reduce itself to sulphurous acid, the process being slow at room temperature and fast with heating. The resultant products are sulphur dioxide and water, the products of decomposition of sulphurous acid H_2SO_3, and also the appropriate sulphate. If the metal is bivalent, the main reaction is as follows:

$$Me + 2H_2SO_4 = MeSO_4 + 2H_2O + SO_2$$

In fact, the reaction is more complicated and a metal sulphide is also formed.

In the above equation sulphur is positively hexavalent and it is reduced to positively tetravalent sulphur:

$$\overset{+6}{S} + 2e = \overset{+4}{S}$$

by taking the required electrons from the metal atoms.

Concentrated sulphuric acid acts similarly on the metals which are stable against the action of dilute sulphuric acid, for example, copper, silver, mercury, and lead.

The action of concentrated sulphuric acid on the most active metals standing at the very top of the electromotive series, potassium, sodium, and calcium, is quite different. In this case positively hexavalent sulphur (+6) is reduced to negatively bivalent sulphur (—2) to form hydrogen sulphide.

The general scheme of such a reaction for a bivalent metal is as this:

$$4\text{Me} = 4\text{Me}^{2+} + 8e \qquad \overset{+6}{\text{S}} + 8e = \text{S}^{2-}$$
$$4\text{Me} + 5\text{H}_2\text{SO}_4 = 4\text{MeSO}_4 + 4\text{H}_2\text{O} + \text{H}_2\text{S}$$

The action of *nitric acid* on various metals is quite diverse and depends on the properties of the metal, concentration of the acid, the temperature, and many other factors. When making equations for the reactions between metals and nitric acid one should remember that $\overset{+5}{\text{N}}$ (in HNO_3) takes electrons from the metal atoms to convert into $\overset{-3}{\text{N}}$ (in NH_3), $\overset{+1}{\text{N}}$ (in N_2O), $\overset{+2}{\text{N}}$ (in NO), and $\overset{+4}{\text{N}}$ (in NO_2). Dilute nitric acid reacts with the metals standing at the top of the electromotive series to form gaseous ammonia NH_3.

Dilute nitric acid forms nitric oxide as it reacts with metals standing farther to the bottom of the electromotive series and less readily giving off their electrons. Concentrated nitric acid is reduced to nitrogen dioxide.

The noble metals which stand in the bottom of the electromotive series (namely, gold and platinum) are stable against the action of nitric acid since their atoms give off their electrons with great difficulty.

In addition to oxides of nitrogen or ammonia, water and nitrates are also produced in the reactions between nitric acid and metals. Nitrates are produced by the metal ion and the acid radical ion NO_3^-. In cases where NH_3 is formed in the reaction, it immediately combines with part of HNO_3 to produce the salt NH_4NO_3. The valence of the nitrogen atom N in the ion NH_4^+, as well as in the molecule NH_3, is minus 3. Some metals standing in the middle of the electromotive series, like aluminium, iron, and chromium, are known to be inactive towards the action of concentrated nitric acid, which is due to the formation of a fast film of an anhydrous oxide on the metal surface which resists the action of the acid.

Here follow examples of typical equations illustrating the reactions between nitric acid and metals forming doubly charged ions Me^{2+}:

Dilute Nitric acid

(a) $4Me = 4Me^{2+} + 8e \qquad \overset{+5}{N} + 8e = \overset{-3}{N}$

$$4Me + 10HNO_3 = NH_4NO_3 + 4Me(NO_3)_2 + 3H_2O$$

(b) $3Me = 3Me^{2+} + 6e \qquad 2\overset{+5}{N} + 6e = 2\overset{+2}{N}$

$$3Me + 8HNO_3 = 2NO + 3Me(NO_3)_2 = 4H_2O$$

(c) $4Me = 4Me^{2+} + 8e \qquad 2\overset{+5}{N} + 8e = 2\overset{+1}{N}$

$$4Me + 10HNO_3 = N_2O + 4Mc(NO_3)_2 + 5H_2O$$

Concentrated Nitric Acid

$$Me = Me^{2+} + 2e \qquad 2\overset{+5}{N} + 2e = 2\overset{+4}{N}$$

$$Me + 4HNO_3 = 2NO_2 + Me(NO_3)_2 + 2H_2O$$

The ions of metals in their lowest valence state can be oxidized into ions of the same metals in their highest valence, for example Fe^{2+} into Fe^{3+} ions:

$$6Fe^{2+} = 6Fe^{3+} + 6e \qquad 2\overset{+5}{N} + 6e = 2\overset{+2}{N}$$

$$3FeSO_4 + 4HNO_3 = NO + Fe_2(SO_4)_3 + Fe(NO_3)_3 + 2H_2O, \quad \text{etc.}$$

42. Physical and Chemical Properties of Metals

9.1. How can the specific physical properties of metals in the solid and liquid states be explained?

9.2. What factors change electric conductivity of metals? Give a detailed explanation.

9.3. Why are metals impermeable to light?

9.4. What is ductility of metals? Which is the most ductile metal?

9.5. What factors are responsible for the differences in the physical properties of metals?

9.6. What metals can be melted in the flame of (a) a gas burner (about 1560°C); (b) an alcohol burner (about 1100°C); (c) a kerosene burner (about 1650°C)?

9.7. What metals are (a) the most fusible; (b) the most refractory; (c) the lightest; (d) the heaviest?

9.8. On what factors do the chemical properties of metals depend?

9.9. What is the electromotive series of metals? How can the presence of hydrogen in the series be explained?

9.10. Consider the metals in the electromotive series and answer the following questions giving the appropriate reaction equations: (a) Which metal is oxidized most readily? (b) The ion of which metal is reduced most easily? (c) Which metals are oxidized in air in normal conditions, which are oxidized with heating and which are not oxidized at all? (d) Which metals can displace hydrogen from water in ordinary conditions, which at elevated temperatures and which do not displace it at all? (e) Which metals displace hydrogen from acids to form the corresponding salts, and which do not?

9.11. How do metals react with dilute and concentrated (a) sulphuric acid; (b) nitric acid? Give a detailed answer.

9.12. What quantity of hydrogen is liberated in the reaction between water and (a) 1.2 g-atoms of potassium; (b) 1.5 g-atoms of sodium; (c) 2 g-atoms of calcium? What volume will these quantities of hydrogen occupy at NTP?

9.13. What quantity of water vapour was decomposed by iron, if (a) 8 kilomoles of hydrogen; (b) 2 m^3 of hydrogen at NTP were liberated?

9.14. Calculate the quantity of pure zinc that can displace from a solution of copper sulphate (a) 3.2 g; (b) 2.5 g-atoms of pure copper. Give molecular and ionic equations.

9.15. What quantity of commercial iron containing 10 per cent of admixtures is required to displace from a solution of copper sulphate (a) 128 g; (b) 10 g-atoms of copper?

9.16. What quantity of silver nitrate $AgNO_3$ was contained in a solution if 4.32 g of silver were displaced from it by copper?

9.17. Write down the equations for the following reactions:

(a) $Mg+H_2SO_4$ (dilute) =

(b) $Al+H_2SO_4$ (dilute) =

(c) $Sn+H_2SO_4$ (dilute) =

(d) $Ag+H_2SO_4$ (concentrated) =

(e) $Hg+H_2SO_4$ (concentrated) =

(f) $Cu+H_2SO_4$ (concentrated) =

(g) $Ca+H_2SO_4$ (concentrated) =

(h) $Na+H_2SO_4$ (concentrated) =

Calculate for each particular case the quantity of a salt produced in the reaction if (a) 40 g of metal; (b) 10 g-atoms of metal; (c) 196 g of the acid; (d) 10 moles of the acid take part in the reaction.

9.18. Write down the equations for the reactions between dilute nitric acid and the following metals (the valence is given in parentheses): (a) zinc (II); (b) copper (II); (c) aluminium (III); (d) sodium (I). Write the equations for the reactions between concentrated nitric acid and (e) copper (II); (f) zinc (II); (g) calcium (II).

43. Magnesium and Its Compounds

9.19. What quantity of magnesium oxide is formed in burning (a) 12 g; (b) 20 g-atoms of magnesium?

9.20. Calculate the quantity of burnt magnesia formed by roasting magnesite containing 92 per cent of magnesium carbonate taken in amounts of (a) 100 kg; (b) 200 tons? What quantity in litres at NTP of carbon dioxide was liberated in each case?

9.21. What quantity in grams of magnesium hydroxide was precipitated by the action of 40 g of a 10 per cent solution of magnesium nitrate on (a) 20 g of a 15 per cent solution of sodium hydroxide; (b) 20 g of a 30 per cent solution of potassium hydroxide? What reactant and in what quantity will remain unreacted?

9.22. As a solution of magnesium chloride is evaporated, the basic salt MgOHCl is formed due to decomposition of the starting salt by water (hydrolysis):

$$MgCl_2+H_2O \rightleftarrows MgOHCl+HCl$$

Sorel cement (magnesium oxychloride cement) is prepared by mixing magnesia with concentrated aqueous solution of magnesium chloride. The mixture soon sets to form a dense and easily polishable mass. The chemistry of cement solidification is as this:

$$MgO + MgCl_2 + H_2O = 2MgOHCl$$

Calculate the quantities of (a) magnesium oxide required to prepare 4 moles of basic magnesium chloride; (b) magnesium chloride required to prepare 306 kg of $MgOHCl$.

9.23. Among natural silicates of magnesium are talcum $3MgO \cdot 4SiO_2 \cdot H_2O$ and asbestos $CaO \cdot 3MgO \cdot 4SiO_2$. Which of these minerals is richer in magnesium?

44. Alkaline-Earth Metals

9.24. What quantity in grams of calcium reacts with (a) 10 moles of water; (b) 144 g of water? What quantity of hydrogen is liberated in each case? What volume will the liberated hydrogen occupy at NTP?

9.25. What quantity of calcium oxide is formed (a) as 4 g-atoms of calcium burn in air; (b) by roasting 200 g of chemically pure chalk; (c) by roasting in a kiln 2 tons of limestone containing 94 per cent of calcium carbonate; (d) by calcining 0.5 kg of marble containing 99 per cent of calcium carbonate and 1 per cent of admixtures?

9.26. What quantity of water is required to prepare calcium hydroxide from calcium oxide taken in amounts of (a) 168 g; (b) 10 moles; (c) 560 kg?

9.27. What quantity of slaked lime is formed by the action of the required quantity of water on one ton of quicklime containing (a) 92 per cent of CaO; (b) 98 per cent of CaO?

9.28. Make out the equations for the reactions which take place in softening hard water with soda.

9.29. Write down the equations for the reactions which take place when heating hard water containing hydrocarbonates of calcium and magnesium.

9.30. Lime water becomes turbid as carbon dioxide is passed through it. Why? Write down the equation of the reaction.

9.31. What process takes place in lime water as carbon dioxide is passed into it for a considerable period of time? Illustrate your answer with the appropriate chemical equations.

9.32. What quantity of calcium carbonate can be prepared by heating (a) 81 g; (b) 5 moles; (c) 2 kilomoles of calcium hydrocarbonate?

9.33. What chemical process takes place when a lime mortar used in building to cement silicate bricks sets in air?

9.34. With what substances of those given below does calcium oxide react: (a) HCl; (b) NaOH; (c) HNO_3; (d) KOH; (e) H_2SO_4; (f) CO_2; (g) SiO_2? Give equations for the appropriate reactions.

9.35. With what substances of those given below does calcium hydroxide react: (a) CO_2; (b) HNO_3; (c) HCl; (d) KOH; (e) H_2SO_4; (f) H_3PO_4?

Write down the equations for the appropriate reactions. Calculate for each particular case gram-molecular quantities of the reaction products produced per mole of calcium hydroxide.

9.36. To improve fertility of acid soils (containing free, mostly organic, acids), chalk, crushed limestone, lime and other calcium compounds are introduced into it. The method is known as *liming*.

What quantity of (a) chalk (96 per cent of $CaCO_3$); (b) limestone (94 per cent of $CaCO_3$) should be introduced into soil on 20 hectares, if the mean requirement for the lime fertilizers per hectare is 3.5 tons calculated with reference to calcium oxide?

9.37. A 5 per cent solution of calcium chloride is used in medicine for injections and per os administration. Calculate (a) the quantity in grams of $CaCl_2 \cdot 6H_2O$ required to prepare 5 kg of the solution of the said concentration; (b) the quantity of gram-molecules of $CaCl_2$ contained in 10 kg of this solution.

9.38. Barium chloride is used in agriculture to fight insects infesting cabbage, cucumbers, and other vegetables. The starting material for preparing barium chloride is barium sulphate, which is first reduced with carbon to barium sulphide:

$$BaSO_4 + 4C = BaS + 4CO$$

Then barium sulphide reacts with hydrochloric acid:

$$BaS + 2HCl = BaCl_2 + H_2S$$

Calculate by using stoichiometric scheme the quantity in kilograms of barium sulphate $BaSO_4$ required to prepare (a) 104 kg; (b) 1 mole of $BaCl_2$.

9.39. Why can baryta water (an aqueous solution of barium hydroxide) be used instead of lime water as a specific reagent for CO_2? Illustrate your answer by the appropriate reaction equations.

45. Aluminium

9.40. Will (a) 50 g; (b) 3 moles; (c) 30 litres (at NTP) of oxygen be sufficient to oxidize 54 g of aluminium?

9.41. What quantities of powdered aluminium and ferriferrous oxide Fe_3O_4 should be mixed together to prepare (a) 107 kg; (b) 2.14 kg of thermite (the mixture $3Fe_3O_4 + + 8Al$)?

9.42. What quantity in grams of iron is obtained by reducing 16 g of ferric oxide by the required quantity of aluminium?

9.43. What quantity in grams of aluminium is required to reduce ferric oxide to obtain (a) 5.6 g; (b) 4 g-atoms of iron?

9.44. 15.7 kg of chromium oxide were reduced by 5 kg of aluminium. What quantity of chromium was obtained by the aluminothermic method? Which of the starting substances was taken in excess?

9.45. 10.8 kg of aluminium and 26.2 kg of manganese dioxide were mixed to prepare manganese by the aluminothermy. Which starting substance and in what quantity was taken in excess?

9.46. Why should aluminium articles be kept away from mercury and its compounds?

9.47. Why should caustic soda (sodium hydroxide NaOH) and also its solutions, especially concentrated, not be kept in aluminium containers?

9.48. Express by chemical equations the process of aluminium combining with (a) chlorine; (b) sulphur; (c) nitrogen; (d) carbon. Calculate for each particular case the quantity in grams of the resultant product assuming that one g-atom of aluminium takes part in the reaction.

9.49. What quantity in grams of aluminium is required to form 0.1 mole of $Al_2(SO_4)_3$? What quantity in millilitres of H_2SO_4 (density 1.44 g/cc) will take part in the reaction?

9.50. Write down the equation for the reaction between aluminium and a solution of sodium hydroxide. What quantity in grams of sodium aluminate can be prepared from 0.5 g of aluminium and the appropriate quantities of sodium hydroxide and water?

9.51. What quantity in grams of aluminium hydroxide will be precipitated by acting with 3 moles of potassium hydroxide on one mole of aluminium nitrate?

9.52. What quantity of alkali is required to form potassium aluminate from one mole of $AlCl_3$?

9.53. Write down the equation for the reaction of formation of sodium aluminate from aluminium hydroxide and caustic soda. What quantity in grams of NaOH reacts with one mole of $Al(OH)_3$ in this reaction?

46. Tin

9.54. The chemical processes taking place in extracting tin from the ore SnO_2 are expressed mainly by the following equations:

$$SnO_2 + 2C = Sn + 2CO, \qquad SnO_2 + 2CO = Sn + 2CO_2$$

Write down electronic equations and prove that both reactions are oxidation-reduction reactions. What is the oxidant and the reductant in these reactions?

Calculate (a) the quantity of tin stone containing 92 per cent of SnO_2 and 8 per cent of gangue which can be reduced by 318 kg of anthracite containing 90 per cent of carbon; by 448 litres (at NTP) of CO; (b) the quantity of the tin stone required to prepare 1.19 tons of tin; 2 kg-atoms of tin. Assume the concentration of admixtures in the ore to be 8 per cent and the yield 92 per cent of theory.

9.55. Tin is dissolved chemically in hydrochloric acid and dilute sulphuric acid. The dissolution is slow in cold and fast with heating. The process is accompanied by liberation of hydrogen:

$$Sn+2HCl=SnCl_2+H_2$$
$$Sn+H_2SO_4=SnSO_4+H_2$$

Write the ionic equations of these reactions.

Calculate (a) the volume of a 28.61 per cent hydrochloric acid required to dissolve 1.5 g-atoms of pure tin; (b) the quantity of a 17.66 per cent sulphuric acid required to liberate 44.8 litres (at NTP) of hydrogen in the reaction with pure tin.

9.56. Concentrated sulphuric acid dissolves chemically tin to form the salt $Sn(SO_4)_2$ and to liberate sulphur dioxide:

$$Sn+4H_2SO_4=Sn(SO_4)_2+2SO_2+4H_2O$$

What quantity of tin is required to prepare this salt in the following amounts: (a) 3.11 g; (b) 2 moles? What quantity in litres of sulphur dioxide at NTP will be liberated in each particular case?

9.57. A cold strongly diluted nitric acid reacts with tin according to the equation:

$$4Sn+10HNO_3=4Sn(NO_3)_2+NH_4NO_3+3H_2O$$

Does tin act like a metal or a nonmetal in this reaction? Give a detailed answer.

Calculate the quantity in grams of nitric acid required (a) to dissolve 4.76 g of tin; (b) to form 48.6 g of the salt $Sn(NO_3)_2$; (c) to form 2.5 moles of the salt NH_4NO_3.

47. Lead

9.58. Lead can be prepared electrolytically from lead chloride $PbCl_2$. What quantity of lead can be prepared from 4 moles of this salt?

9.59. Acids readily react with lead oxide PbO to form salts. Write down the equation for the reaction between lead oxide and (a) hydrochloric acid; (b) sulphuric acid; (c) nitric acid and calculate for each particular case the quantity of the salt that will be formed by the action of the appropriate quantity of the acids on PbO, if the oxide contains 0.7 g-atom of lead.

9.60. What quantity in grams of lead hydroxide $Pb(OH)_2$ can be prepared from 2 moles of the salt $Pb(NO_3)_2$ by acting on it with the required quantities of (a) sodium hydroxide; (b) potassium hydroxide?

9.61. Lead hydroxide $Pb(OH)_2$ is dissolved chemically in alkali solutions to produce plumbites. Write down the molecular and ionic equations for the reactions of formation of sodium plumbite and potassium plumbite. Does lead hydroxide act as a base or an acid in these reactions?

Calculate (a) the quantity in millilitres of a 10 per cent solution of sodium hydroxide which is formed by the action of 2.85 g of sodium plumbite on lead hydroxide (for the density of NaOH solutions see Appendix, Table 5); (b) the quantity in grams of potassium plumbite formed by the action of excess potassium hydroxide solution on 0.25 mole of lead hydroxide.

48. Chromium

9.62. What quantity of aluminium is required to prepare 4 g-atoms of chromium from chromium oxide Cr_2O_3 by the aluminothermic method?

9.63. What quantity in grams of chromium can be obtained from the appropriate quantity of chromite reducing it by 8 kg-atoms of carbon, if we assume that the ore contains (a) 98 per cent; (b) 90 per cent; (c) 82 per cent of $Fe(CrO_2)_2$?

9.64. In industry chromium oxide Cr_2O_3 is prepared by calcining a mixture of salts of chromic acid H_2CrO_4 or dichromic acid $H_2Cr_2O_7$ with carbon or sulphur, for example, potassium dichromate with carbon:

$$K_2Cr_2O_7 + 2C = Cr_2O_3 + K_2CO_3 + CO$$

Calculate: (a) the quantity of carbon required to reduce $K_2Cr_2O_7$ to prepare 2 moles of Cr_2O_3; (b) the quantity of chromium oxide that can be obtained by reducing 4 moles of potassium dichromate by the appropriate quantity of carbon.

9.65. Write down the equation of the reaction of dissolution of chromium hydroxide $Cr(OH)_3$ in hydrochloric acid. Calculate the quantity of chromium chloride $CrCl_3$ that is produced from 6 moles of chromium hydroxide and the required quantity of hydrochloric acid.

9.66. Chromates and bichromates are readily interconvertible in different media. Bichromates are stable in an acid medium, e.g.

$$2K_2CrO_4 + H_2SO_4 = K_2Cr_2O_7 + K_2SO_4 + H_2O$$

In an alkaline medium bichromates are converted into chromates:

$$K_2Cr_2O_7 + 2KOH = 2K_2CrO_4 + H_2O$$

Write down both equations in the ionic form (complete and concise). Identify the types of the reactions.

Calculate (a) the quantity in grams of sulphuric acid required to convert 0.5 mole of K_2CrO_4 into potassium bichromate; (b) the quantity in grams of potassium hydroxide required for complete conversion of 0.1 mole of $K_2Cr_2O_7$ into the corresponding quantity of potassium chromate.

9.67. Give the ionic equation for the following reaction:

$$2CrO_3 + 3Na_2SO_3 + 3H_2SO_4 = 3Na_2SO_4 + Cr_2(SO_4)_3 + 3H_2O$$

What quantity in grams of chromium sulphate is formed from 4 moles of chromic anhydride, the appropriate quantity of sulphuric acid and sodium sulphite?

What quantity in grams of sulphuric acid reacts with 2 g of chromic anhydride and the required quantity of sodium sulphite to form the quantity of sodium sulphate corresponding to the above reaction equation?

49. Manganese

9.68. Write down the molecular, ionic and electronic equations for the reactions of interaction be ween hydrochloric acid and (a) MnO; (b) MnO_2. Write down also the ionic equation for the first and the electronic equations for the second reaction.

9.69. What quantity in grams of manganese sulphate $MnSO_4$ is formed on complete dissolution of 2 g-atoms of manganese in dilute sulphuric acid?

9.70. What quantity in grams of potassium permanganate $KMnO_4$ is required to oxidize completely 0.5 mole of sodium sulphite Na_2SO_3 into sodium sulphate Na_2SO_4 in the presence of sulphuric acid? The equation of the reaction is:

$$5Na_2SO_3+2KMnO_4+3H_2SO_4=5Na_2SO_4+K_2SO_4+2MnSO_4+3H_2O$$

Write the ionic and also the electronic equations of this reaction.

9.71. The oxidation of sodium sulphite Na_2SO_3 with potassium permanganate $KMnO_4$ in a neutral medium is expressed by the equation:

$$3Na_2SO_3+2KMnO_4+H_2O=3Na_2SO_4+2MnO_2+2KOH$$

Write the ionic form for this equation and calculate the quantity in grams of sodium sulphite which is oxidized by the appropriate quantity of potassium permanganate if 42.6 g of sodium sulphate are formed.

9.72. The oxidation of sodium sulphite Na_2SO_3 with potassium permanganate $KMnO_4$ in a strongly alkaline medium in the presence of a small quantity of a reducing agent (in this particular case Na_2SO_3) is expressed by the reaction equation:

$$Na_2SO_3+2KMnO_4+2KOH=Na_2SO_4+2K_2MnO_4+H_2O$$

Write down the ionic and electronic equations for this reaction. Calculate the quantity in grams of potassium manganate K_2MnO_4 which is formed during oxidation of 12.6 g of Na_2SO_3 with the appropriate quantity of the permanganate.

9.73. In the reaction between potassium permanganate $KMnO_4$ and concentrated sulphuric acid manganese heptoxide Mn_2O_7, potassium sulphate K_2SO_4 and water are formed.

Write down the equation for this reaction and select proper coefficients basing on the electronic equations. Calculate the quantity of manganese heptoxide which is formed from 0.5 mole of $KMnO_4$ and the required quantity of sulphuric acid.

50. Iron

9.74. What quantity of ferriferrous oxide Fe_3O_4 is formed from 6 g-atoms of iron as they burn completely in air? Express your answer in grams and moles.

9.75. What quantity in moles of hydrogen is displaced by 1.5 kg-atoms of iron in the reaction with stoichiometric quantity of water at high temperature?

9.76. During dissolution of pure iron in dilute hydrochloric acid 11.2 litres of hydrogen (at NTP) were liberated. What quantity of iron took part in the reaction?

9.77. Pure iron reacted with dilute sulphuric acid to form 0.1 mole of $FeSO_4$ in solution. What volume of hydrogen (at NTP) was liberated in the reaction?

9.78. By the action of stoichiometric quantity of sodium hydroxide on a solution of $FeSO_4$ 18 g of $Fe(OH)_2$ were precipitated. What quantity in moles of $FeSO_4$ took part in the reaction?

9.79. In the reaction between ferric chloride and potassium hydroxide 10.7 g of ferric hydroxide were precipitated. What quantity in moles of $FeCl_3$ and KOH took part in the reaction?

9.80. What quantity of Turnbull's blue is formed in the reaction between 1.5 moles of $FeSO_4$ and stoichiometric quantity of potassium ferricyanide? Express your answer in moles and grams.

9.81. What quantity of potassium ferrocyanide is required to form 0.5 mole of Berlin blue in the reaction with ferric chloride? Express your answer in grams and moles.

9.82. What quantity of Berlin blue is formed in the reaction between 0.25 mole of $FeCl_3$ and the appropriate quantity of potassium ferrocyanide? Express your answer in moles and grams.

9.83. What quantity of pig iron containing 94 per cent of iron can be smelted from 1,000 tons of red iron ore containing 20 per cent of gangue?

9.84. What quantity in tons of magnetite containing 90 per cent of Fe_3O_4 is required to smelt out 2 tons of pig iron containing 93 per cent of iron, the yield of the product being 92 per cent of theory?

9.85. When an iron ore is analysed for the presence of iron in the form of its carbonate, a sample of the ore is crushed in a mortar together with a few crystals of $KHSO_4$. The iron is thus converted from the insoluble $FeCO_3$ into soluble $FeSO_4$:

$$FeCO_3 + 2KHSO_4 = K_2SO_4 + FeSO_4 + H_2O + CO_2$$

Iron is then determined quantitatively in the formed ferrous sulphate.

Calculate the quantity in grams of ferrous carbonate that can be converted into 6.08 g of ferrous sulphate.

9.86. The efficiency of a blast furnace is characterized by the quantity of tons of pig iron that is smelted per day and by the utilization coefficient which is the ratio of the useful capacity of the furnace in cubic metres to the daily output of pig iron in tons. The lower the coefficient, the higher the efficiency of the furnace. (a) If the useful capacity of the furnace is 1,200 cubic metres, and the utilization coefficient is 0.7, what is the daily output of the furnace? (b) The useful capacity of the blast furnace is 1,000 cubic metres, the utilization coefficient is 0.67; what is the output of the furnace in tons per day?

9.87. The process of ferric oxide Fe_2O_3 reduction can be expressed as this:

$$Fe_2O_3 \longrightarrow Fe_3O_4 \longrightarrow FeO \longrightarrow Fe$$

Write down the equations for the corresponding reactions in which iron oxides are reduced by (a) carbon monoxide; (b) hydrogen. Calculate the quantity of iron that can be obtained from 2 tons of hematite containing 88 per cent of ferric oxide, the yield being 92 per cent.

9.88. 240 kg of an iron alloy with chromium (ferrochrome) containing 65 per cent of chromium were smelted out of one ton of chromite $Fe(CrO_2)_2$. Calculate the admixtures content of the ore.

9.89. Sulphuric acid (sometimes mixed with other acids and substances) is used for cleaning surfaces of steel articles of rust. This operation (pickling) is employed in industry to pretreat steel articles before electroplating or coating with paints. Write down the equation for the reaction of dissolution of ferric oxide in sulphuric acid. What quantity of ferric oxide is formed by dissolving in sulphuric acid (a) 0.5 kilomole; (b) 200 kg of ferric sulphate?

51. Copper

9.90. Copper stands below hydrogen in the electromotive series. Therefore, dilute acids HCl and H_2SO_4 do not act on copper, but in the presence of atmospheric oxygen copper is dissolved in them to form the corresponding salts, for example, cupric chloride $CuCl_2$:

$$2Cu+4HCl+O_2=2CuCl_2+2H_2O$$

Explain this phenomenon.

What quantity of $CuCl_2$ can be prepared from 12 g of copper containing 10 per cent of admixtures and the appropriate quantity of hydrochloric acid?

9.91. What quantity in grams of cupric nitrate $Cu(NO_3)_2$ is formed by heating 6.4 g of pure copper with the required quantity of dilute nitric acid? What gas and in what quantity (at NTP) is liberated in the reaction?

9.92. What quantity in grams of the salt $Cu(NO_3)_2$ is formed by heating 32 g of pure copper with the appropriate quantity of nitric acid having the density of 1.52 g/cc? What gas and in what quantity is liberated in the process?

9.93. What quantity in grams of copper sulphate is prepared by heating 12.8 g of pure copper with the required quantity of concentrated sulphuric acid? What gas and in what quantity is liberated in the process? Express your answer in grams and in volume units (at NTP).

9.94. How can cupric oxide be prepared from copper sulphate? What quantity of the oxide can be prepared from 100 g of a 20 per cent solution of copper sulphate?

9.95. 5 g of $Cu(NO_3)_2$ and 2 g of sodium hydroxide reacted to form copper hydroxide. What substance remained in excess after mixing their solutions? What is the mass of the precipitate?

9.96. What quantity in grams of copper hydroxide is prepared from 16 g of $CuSO_4$ and 12 g of KOH? What substance and in what quantity remains in excess?

9.97. A white powder is supposed to be anhydrous copper sulphate. How can the substance be identified?

9.98. Basic copper carbonate $(CuOH)_2CO_3$ (or $CuCO_3\cdot Cu(OH)_2$) can be prepared in the laboratory by reacting copper sulphate with soda:

$$2CuSO_4+2Na_2CO_3+H_2O=CuCO_3\cdot Cu(OH)_2+2Na_2SO_4+CO_2$$

Calculate (a) the quantity in grams of soda that reacts with 160 g of copper sulphate to form basic copper carbonate;

(b) the quantity in grams of a 20 per cent solution of $CuSO_4$ that should be taken to prepare 11.1 g of basic copper carbonate.

52. Silver

9.99. Silver articles, ancient coins, and the like darken with age. Why?

9.100. What quantity of sulphur dioxide is liberated by heating 21.6 g of pure silver with the appropriate quantity of concentrated sulphuric acid, if silver sulphate and water are also produced in the reaction?

9.101. What quantity of silver oxide can be prepared by acting with sufficient quantity of potassium hydroxide solution on 0.5 mole of silver nitrate in an aqueous solution?

9.102. What quantity in grams of a 20 per cent solution of $AgNO_3$ forms 2.87 g of silver chloride by the action on a solution of sodium chloride?

9.103. What quantity in grams of silver bromide was precipitated by adding excessive quantity of silver nitrate to 238 g of a 10 per cent solution of potassium bromide?

9.104. 113.4 g of a 15 per cent solution of $AgNO_3$ and 180 g of a 10 per cent solution of KI were reacted to prepare silver iodide. What quantity of AgI was prepared? What reactant remained in excess?

53. Gold

9.105. The process of gold dissolution in aqua regia is expressed by the following equation:

$$Au + 3HCl + HNO_3 = AuCl_3 + NO + 2H_2O$$

What quantity of gold chloride is formed by dissolving in aqua regia (a) 10 g-atoms; (b) 1.97 kg of gold? What quantity of nitric oxide is liberated during dissolution of 0.197 g of gold in the appropriate quantity of aqua regia?

54. Zinc

9.106. What quantity of zinc can be prepared by reducing with carbon (a) 8.1 tons; (b) 10 kg-atoms; (c) 4.05 g of pure zinc oxide?

9.107. What quantity of zinc can be prepared by reducing with carbon pure zinc oxide in the following quantities: (a) 324 kg; (b) 2.5 kilomoles; (c) 10 kilomoles, the yield of the product being 92 per cent?

9.108. What quantity of zinc can be prepared from one ton of zinc oxide containing 2 per cent of admixtures if the yield of zinc is 96 per cent?

9.109. What quantity of pure zinc oxide should be reduced with carbon to prepare (a) 130 kg; (b) 10 kg-atoms of zinc?

9.110. What quantity of zinc can be obtained from 970 kg of zinc blende containing 90 per cent of zinc sulphide if the yield of zinc is 98 per cent?

9.111. Write down the equations for the reactions by which zinc can be recovered from smithsonite.

9.112. What quantity of zinc can be prepared from (a) 0.5 ton; (b) 250 kg; (c) 126 kg of smithsonite if the ore contains 94 per cent of zinc carbonate and the yield of zinc is 98 per cent of theory?

9.113. Zinc reacts with dilute sulphuric acid to liberate hydrogen and to form zinc sulphate.

Calculate (a) the quantity in litres of H_2SO_4 (density 1.125 g/cc) which reacts with zinc to liberate 20 g of hydrogen; 10 moles of hydrogen; 100 litres of hydrogen (at NTP); (b) the quantity of zinc sulphate which is formed in the reaction between 132 g of commercial zinc containing 2 per cent of admixtures and 200 g of sulphuric acid. What starting substance will remain in excess?

9.114. What quantity of commercial zinc containing 4 per cent of admixtures should be reacted with the appropriate quantity of hydrochloric acid to prepare (a) 13.6 g; (b) 2 moles of zinc chloride?

9.115. The reaction between zinc dust and strongly diluted nitric acid is expressed by the equation:

$$4Zn + 10HNO_3 = 4Zn(NO_3)_2 + NH_4NO_3 + 3H_2O$$

What quantity of zinc nitrate is formed from (a) 2 g-atoms of pure zinc; (b) 26.4 g of commercial zinc containing 2 per cent of admixtures; (c) what quantity in litres of nitric acid (density 1.12 g/cc) is required to prepare 75.6 g of zinc nitrate?

9.116. Zinc is dissolved chemically in alkalis to liberate hydrogen and to form soluble salts known as zincates:

$$Zn + 2NaOH = Na_2ZnO_2 + H_2$$

What properties of zinc are illustrated by this reaction? Write down the equation of this reaction in the ionic form.

What quantity of zinc is required to form sodium zincate (in solution) in amounts of (a) 28.6 g; (b) 3 moles?

9.117. Zinc phosphide Zn_3P_2 is used to poison baits in agriculture to control rodents, such as gophers. The preparation is obtained by fusing zinc with red phosphorus. (Write down the reaction equation.) When in the stomach of the animal, zinc phosphide is decomposed by the hydrochloric acid of the gastric juice:

$$Zn_3P_2 + 6HCl = 3ZnCl_2 + 2PH_3$$

Hydrogen phosphide that is formed in this reaction kills the rodent.

Calculate the quantity of PH_3 which is liberated in the reaction between sufficient quantity of hydrochloric acid and (a) 3 moles; (b) 5.14 g of zinc phosphide.

55. Mercury

9.118. As cinnabar HgS is roasted in the furnace, mercury is liberated in the free state, whereas many other sulphide ores, for example, ZnS, FeS_2, are roasted to form oxides of the corresponding metals. Explain this phenomenon.

9.119. Why cannot mercury thermometers be used to measure low temperatures?

9.120. Why should gold and gold articles be kept away from contact with mercury?

9.121. Mercury forms two chlorides, namely, calomel HgCl and corrosive sublimate $HgCl_2$. Sublimate is a very strong poison. Calomel is used in medicine as a strong laxative in special cases, e.g. in poisoning, etc. How can this difference in the action of the two salts on man be explained?

9.122. Mercury and its vapour are known to be very strong poisons. Spilt mercury should therefore be carefully collected. Tin foil is readily wettened by mercury and is therefore used to extract its finest drops from cracks in the floor. The irrecoverable remains of mercury should be powdered over with sulphur. Explain the special action of tin foil on mercury. Why should sulphur be used to deactivate mercury?

56. Laboratory Exercises

9.123. Put pieces of copper wire (or chips) into solutions of the following salts: (a) silver nitrate $AgNO_3$; (b) lead acetate $Pb(C_2H_3O_2)_2$; (c) ferric chloride $FeCl_3$. What phenomena are observed? Explain them. Write down the molecular and ionic equations for the case where reaction takes place.

9.124. Place a solution of lead nitrate $Pb(NO_3)_2$ into three test-tubes and add zinc into the first, iron into the second, and copper into the third test-tube. Observe the reactions. Write down the molecular and ionic equations for the reactions.

9.125. By using copper identify concentrated (a) hydrochloric acid; (b) nitric acid; (c) sulphuric acid in test-tubes. Write down the reaction equations. Make out electronic equations of the reactions.

9.126. An unknown substance is supposed to be quicklime. What reaction can be used to identify the substance?

9.127. Prove experimentally that a sample of quicklime contains a small admixture of calcium carbonate.

9.128. A given sample of hard water contains magnesium hydrocarbonate and calcium sulphate. Soften the water. Explain the softening effect of the methods used.

9.129. Accomplish two reactions in which aluminium atoms would be converted into ions.

9.130. A solution contains a mixture of two salts selected from the following list: $BaCl_2$, $CuCl_2$, $AlCl_3$, and $FeCl_3$. Determine experimentally which of these salts are present in the solution.

9.131. A solution contains a mixture of two salts selected from $(NH_4)_2SO_4$, $CuSO_4$, $CuCl_2$, and $FeCl_3$. Determine experimentally what salts are present in the solution.

9.132. Determine experimentally which of two given salts is aluminium sulphate and which is calcium chloride.

9.133. A solution contains ions of silver and zinc. Remove from the solution first silver ions and then zinc ions.

9.134. Zinc vitriol $ZnSO_4 \cdot 7H_2O$ is available. Prepare 200 g of a 50 per cent zinc sulphate solution.

9.135. A solution of zinc sulphate $ZnSO_4$ is available. Prepare zinc hydroxide and prove experimentally the amphoteric properties of the obtained hydroxide.

9.136. Prove experimentally the amphoteric properties of aluminium hydroxide.

9.137. Prepare sodium aluminate from aluminium by two methods.

9.138. By using ammonium hydroxide prepare aluminium hydroxide and test it for solubility in excess ammonium hydroxide.

9.139. Accomplish the following conversions:

$$Al \rightarrow Al(NO_3)_3 \rightarrow Al_2(SO_4)_3$$

9.140. Prove by specific reactions the composition of copper sulphate.

9.141. Prove experimentally the reducing power of iron atoms.

9.142. Prepare ferrous hydroxide from green vitriol. What quantity in grams of ferrous hydroxide can be prepared from 2 g of green vitriol?

9.143. Prepare ferric hydroxide from ferric sulphate. What quantity in grams of ferric sulphate is required to prepare 4 moles of ferric hydroxide?

9.144. Ferric chloride is available. Prepare ferric hydroxide and act with hydrochloric acid on it. Write down the reaction equations.

57. Review Problems

9.145. Compare the design and the operation of a lime kiln, a producer furnace, and a blast furnace. What is common in the design of these furnaces and the processes that take place in them?

9.146. What quantity of ferrous sulphate can be preparep by dissolving the required quantity of pure iron in 30 ml of a 24.76 per cent acid?

9.147. 20 g of a 15 per cent solution of ferrous sulphate were acted upon with 40 ml of a 12 per cent solution of potassium hydroxide (for the density of potassium hydroxide solution see Appendix, Table 5). What quantity in grams of ferrous hydroxide was precipitated in this reaction? What substance and in what quantity remained in excess?

9.148. What quantity in grams of ferric chloride $FeCl_3$ in solution reacts with 40 ml of a 16 per cent solution of sodium hydroxide (for the density see Appendix, Table 5) to form 4.84 g of ferric hydroxide? What quantity of sodium hydroxide will remain unreacted?

9.149. If a precipitate of ferrous hydroxide is shaken vigorously in a test-tube, the hydroxide is oxidized by atmospheric oxygen and water into ferric hydroxide:

$$4Fe(OH)_2 + 2H_2O + O_2 = 4Fe(OH)_3$$

What quantity in grams of free oxygen is required to convert 18 g of ferrous hydroxide into ferric hydroxide?

9.150. Write down the electronic equations for the reaction:

$$2FeCl_2 + Cl_2 = 2FeCl_3$$

9.151. What quantity of $FeCl_3$ was contained in a solution if ferric hydroxide was precipitated by the action of NH_4OH solution, and 0.95 g of Fe_2O_3 was obtained by decomposing this precipitate?

CHAPTER TEN

HYDROCARBONS

58. Hydrocarbons

10.1. Write down the equation for the reaction of preparing methane from sodium acetate and sodium hydroxide. Calculate the quantity of methane that can be prepared from 3 moles of the salt. Express your answer in (a) grams; (b) gram-molecules; (c) litres at NTP.

10.2. Write down the equation for synthesis of methane from hydrogen and carbon. What quantity of hydrogen is required to synthesize 4 moles of methane, if the yield is 98 per cent of theory?

10.3. Calculate the following constants for methane: (a) density with respect to hydrogen; (b) density with respect to air; (c) volume occupied by its one gram at NTP; (d) the mass of one litre at NTP.

10.4. Which gas is heavier, methane, ammonia, or nitric oxide?

10.5. What quantity of oxygen is required to burn (a) 80 g; (b) 10 moles; (c) 20 litres (at NTP) of methane?

10.6. 160 g of methane were burned. What quantity of oxygen took part in the reaction?

10.7. What volume of air (the oxygen content of the air is about 21 per cent) is required to burn completely (a) 8 moles; (b) 320 kg; (c) 224 litres of methane (at NTP).

10.8. What quantity of carbon dioxide is formed during burning of (a) 48 g of methane; (b) 112 litres of methane (at NTP)?

10.9. Methane can be decomposed in the flame of an electric arc into carbon (soot) and hydrogen. What quantity of soot can be prepared from one kilogram of methane?

10.10. Write down the equation for the reaction of formation of methyl chloride by chlorination of methane. What quantity in grams of methyl chloride can be prepared from (a) 80 g; (b) 12 moles; (c) 10 litres of methane (at NTP)?

10.11. There are 124 kg of methane. What quantity of (a) chloroform; (b) carbon tetrachloride (at the yield of 98 per cent) can be produced from this quantity by the chlorination method?

10.12. When exposed to sun light, chlorine reacts with methane with an explosion. The reaction equation is:

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

What quantity of chlorine is required to displace all carbon in 48 g of methane?

10.13. What quantity of free carbon is formed by the action of 67.2 litres of chlorine (at NTP) in direct light on (a) 24 g of methane (the yield should be assumed 100 per cent); (b) 1.5 moles of methane (at the yield of 96 per cent)? The reaction equation is given in the previous problem.

10.14. What quantity of metallic sodium is required to prepare by Würtz's reaction (a) 0.25 mole of ethane; (b) 0.5 mole of propane?

10.15. What reactions (give the appropriate structural equations) should be employed (by Würtz's reaction) to prepare: (a) normal butane; (b) isobutane; (c) normal pentane?

10.16. What quantity of oxygen is required to burn: (a) 120 g of ethane; (b) 2.2 g of propane; (c) 58 g of butane? Express your answer in units of volume at NTP and in mass units.

10.17. What quantity in litres of air at NTP containing 21 per cent of oxygen is required to burn completely (a) 5 moles of ethane; (b) 6 moles of propane; (c) 7 moles of butane?

10.18. What quantity in grams, gram-molecules and litres at NTP of carbon dioxide is formed by burning 10 moles of (a) ethane; (b) propane; (c) butane?

10.19. Calculate the following characteristics for ethane: (a) density with respect to hydrogen; (b) density with respect to air; (c) mass of one litre at NTP; (d) volume of one gram at NTP.

10.20. Calculate the following physical constants for propane: (a) density with respect to hydrogen; (b) density with respect to air; (c) mass of one litre at NTP; (d) volume of one gram at NTP.

10.21. What volume do (a) 0.25 mole of methane; (b) 0.1 kilomole of ethane; (c) 4 moles of propane occupy at NTP?

10.22. Write down with structural formulas the equations for preparing (a) ethyl chloride; (b) propyl bromide; (c) primary butyl chloride (with a chlorine atom at the extreme carbon atom).

10.23. Propane was brominated into 246 g of propyl bromide (the yield of the product was 100 per cent). What quantity of propane took part in this reaction?

10.24. Calculate the percentage composition of (a) propyl chloride; (b) butyl iodide; (c) amyl bromide.

10.25. Write down the equations for the following reactions:

(a) $C_2H_6 \rightarrow C_2H_5Cl \rightarrow C_3H_8 \rightarrow C_3H_7Br$

(b) $C_5H_{12} \rightarrow C_5H_{11}Cl \rightarrow C_6H_{14} \rightarrow C_6H_{13}Cl$

(c) $C_4H_{10} \rightarrow C_4H_9Br \rightarrow C_5H_{12} \rightarrow C_5H_{11}Cl$

10.26. What quantity in litres at NTP of (a) oxygen; (b) air is required to burn one cubic metre of a gaseous mixture containing 80 per cent of methane, 10 per cent of ethane, 6 per cent of hydrogen and 4 per cent of nitrogen at NTP (per cent by volume)? Assume the oxygen content of the air to be 21 per cent.

10.27. Natural gas from a given deposit contains 85 per cent of methane, 8 per cent of ethane, 2 per cent of propane, 2 per cent of nitrogen and 3 per cent of carbon dioxide (per cent by volume). What volume of air is required to burn one cubic metre of this gas? Assume the oxygen content of the air to be 21 per cent.

10.28. Write down the equations for the following reactions:

(a) $C \rightarrow CH_4 \rightarrow CH_3Cl \rightarrow C_3H_8 \rightarrow C_3H_7Br$

(b) $CH_4 \rightarrow CH_3Br \rightarrow C_2H_6 \rightarrow C_2H_5Cl$

(c) $CH_4 \rightarrow C \rightarrow CH_4 \rightarrow CH_3Cl$

10.29. Write down the molecular and structural formulas of the following substances: (a) diiodomethane; (b) ethyl chloride; (c) 1,2-dibromobutane; (d) normal hexane; (e) isopentane; (f) primary amyl iodide.

10.30. Write down the equation for the reaction of preparing ethylene from ethyl alcohol with concentrated sulphuric acid. What quantity of alcohol is required to prepare (a) 10 moles; (b) 560 g; (c) 1.12 litres at NTP of ethylene?

10.31. Calculate the following characteristics for ethylene: (a) density with respect to hydrogen; (b) density with respect to air; (c) mass of one litre at NTP; (d) volume of one gram at NTP.

10.32. What quantity of oxygen is required for complete burning of 4 moles of ethylene?

10.33. What quantity of air is required to burn completely 10 litres of ethylene (at NTP)?

10.34. What quantity in kilograms of 1,2-dichloroethane can be prepared from 112 kg of ethylene?

10.35. Write down the molecular and structural formulas of (a) propylene; (b) vinyl chloride; (c) divinyl (butadiene); (d) isoprene.

10.36. Calculate the following physical constants for acetylene: (a) density with respect to hydrogen; (b) density with respect to air; (c) mass of one litre at NTP; (d) volume of one gram (at NTP).

10.37. What quantity of acetylene is formed by the reaction between 0.5 kilomole of pure calcium carbide and the appropriate quantity of water?

10.38. What quantity of commercial calcium carbide containing 92 per cent of CaC_2 reacts with the required quantity of water to form (a) 2 kilomoles; (b) 13 kg; (c) 1 m^3 at NTP of acetylene?

10.39. What quantities of (a) oxygen; (b) air are required for complete burning of 2 m^3 of acetylene (at NTP)?

10.40. Write down the equations for the following transformations:

$$\text{(a)}\quad C_2H_2 \longrightarrow C_2H_4 \longrightarrow C_2H_6$$

$$\text{(b)}\quad C_2H_2 \longrightarrow CH_2{=}CHCl$$

Calculate for each reaction the quantities of the product formed from 0.2 mole of the starting substance.

10.41. Write down the equation for the process of isoprene polymerization into rubber.

10.42. What quantity of benzene can be synthesized from (a) 390 g; (b) 6 moles; (c) 201.6 litres (at NTP) of acetylene?

10.43. What volume of acetylene at NTP is required to polymerize into (a) 312 g; (b) 20 moles of benzene?

10.44. What volume of (a) oxygen; (b) air is required for complete burning of 0.2 kg of benzene?

10.45. What quantity in grams of hydrogen reacts with 70.2 g of benzene in the preparation of hexamethylene C_6H_{12}?

10.46. When illuminated, chlorine reacts with benzene to form hexachlorane:

$$C_6H_6 + 3Cl_2 \longrightarrow C_6H_6Cl_6$$

Write down with structural formulas the equation of the reaction.

What quantity of hexachlorane is formed by the action of the appropriate quantity of chlorine on (a) 4 kilomoles of benzene; (b) 156 kg of benzene? (Assume the yield of benzene 100 per cent.)

10.47. Calculate the density of benzene vapour with respect to (a) hydrogen; (b) air.

10.48. What quantity of chlorobenzene C_6H_5Cl can be prepared by the reaction between (a) 39 g of benzene and the required quantity of chlorine; (b) 8 moles of benzene and the required quantity of chlorine?

10.49. What quantity of bromobenzene can be prepared by the reaction between 156 g of benzene and 325 g of bromine? What substance will remain in excess?

10.50. 7.8 g of benzene react with bromine to form 15 g of bromobenzene. Calculate the yield of C_6H_5Br in per cent of theory.

10.51. Write down the equation for the polymerization of phenylethylene, otherwise known as styrene.

59. Laboratory Exercises

10.52. Prove experimentally that the given liquid is an unsaturated compound. Explain the experiment.

10.53. Accomplish the reactions by which pure calcium carbide can be distinguished from chalk. Write down the equations for these reactions.

10.54. Prove experimentally that a given sample of benzene contains unsaturated hydrocarbons.

CHAPTER ELEVEN

ALCOHOLS. PHENOLS. ALDEHYDES

60. Alcohols

11.1. While having hydroxyl groups, alcohols are not electrolytes. Why?

11.2. Where does the name alcohol derive from?

11.3. What quantity in grams of ammonia solution of silver oxide $[Ag(NH_3)_2]OH$ reacts with the appropriate quantity of ethyl iodide to form 230 g of ethyl alcohol? The reaction equation is:

$$Ag[(NH_3)_2]OH + C_2H_5I \longrightarrow AgI + 2NH_3 + C_2H_5OH$$

11.4. What quantity in grams of propyl iodide is formed in the reaction between 186 g of propyl alcohol and the appropriate quantity of potassium hydroxide? Assume the yield of the alcohol to be 98 per cent of theory.

11.5. What quantity of primary butyl alcohol is formed in the reaction between a small excess of sodium hydroxide solution and (a) 4.2 moles; (b) 274 g of primary butyl bromide?

11.6. Give examples of (a) saturated monoatomic; (b) saturated diatomic; (c) saturated triatomic alcohols. Calculate the percentage content of carbon in each alcohol.

11.7. What substances are formed during burning of saturated monoatomic alcohols? Write down the equations for the reaction of burning of the following alcohols: (a) methyl alcohol; (b) ethyl alcohol; (c) propyl alcohol. Calculate gram-molecular quantities of substances that are produced during burning of 0.1 kilomole of each of the above named alcohols.

11.8. Alcohols do not conduct electricity, whereas alkalis, also having hydroxyl, conduct electricity in the molten state and in aqueous solutions. Explain this phenomenon.

11.9. Write down the molecular and structural formulas for the following alcohols: (a) propyl alcohol; (b) isopropyl alcohol; (c) normal primary butyl alcohol; (d) primary isobutyl alcohol; (e) primary normal amyl alcohol; (f) secondary isoamyl alcohol.

11.10. Write down the equations for the reactions by which (a) sodium methylate; (b) sodium ethylate; (c) potassium propylate are produced. Calculate for each particular case the gram-molecular quantities of the alcoholates formed from 0.5 mole of the corresponding alcohols.

11.11. What quantity in grams of ethyl alcohol reacts with a slight excess of potassium to liberate (a) 25 moles; (b) 200 g; (c) 2.5 litres at NTP of hydrogen?

11.12. When heated ethyl alcohol reacts with hydrobromic acid to form 218 g of ethyl bromide. What quantity of the alcohol takes part in the reaction?

11.13. Methyl alcohol reacts with hydriodic acid to form 71 g of methyl iodide. What quantity of the alcohol takes part in the reaction?

11.14. Ethyl alcohol is dehydrated to yield ethylene in the following amounts: (a) 4.4 moles; (b) 56 g; (c) 5 litres at NTP. What quantity of the alcohol is consumed in each reaction?

11.15. Calculate the density with respect to hydrogen of vapours of (a) methyl alcohol; (b) ethyl alcohol; (c) propyl alcohol.

11.16. What is the density with respect to air of vapours of (a) methyl alcohol; (b) ethyl alcohol; (c) propyl alcohol?

11.17. What is the mass at NTP of one litre of vapours of (a) methyl alcohol; (b) ethyl alcohol; (c) propyl alcohol?

11.18. What volume at NTP does one gram of vapour of (a) methyl alcohol; (b) ethyl alcohol; (c) propyl alcohol occupy?

11.19. Methyl alcohol can be synthesized by the reaction

$$CO + 2H_2 \longrightarrow CH_3OH$$

The reaction is effected with heating (350-400°C), under pressure (200-1,000 atm) and in the presence of catalysts. What quantity of methyl alcohol can be prepared from (a) 3 moles of CO; (b) 112 g of CO; (c) 1,120 litres of CO (at NTP)?

11.20. Synthetic ethyl alcohol is prepared by hydration of ethylene. Write down the equation for this reaction and calculate (a) the quantity in kilograms of ethylene required to prepare 23 kg of alcohol at the yield of 98 per cent; (b) the quantity of water that reacts with 112 g of ethylene.

11.21. An alcohol containing water is dehydrated by boiling with calcium carbide. What quantity in grams of water can be removed from the alcohol with (a) 32 g of pure calcium carbide; (b) 60 g of commercial product containing 95 per cent of CaC_2?

61. Phenols

11.22. What quantity in grams of sodium phenolate can be prepared from 9.4 g of phenol by reacting it with the appropriate quantity of sodium hydroxide?

11.23. What quantity in grams of phenol reacts with potassium hydroxide if 26.4 g of potassium phenolate are formed in the reaction?

11.24. What quantity in grams of sodium hydroxide reacts with 4 moles of phenol to give 3 moles of sodium phenolate? What reactant and in what quantity remains unreacted?

11.25. What quantity in grams of phenol can be prepared by the action of the appropriate quantity of hydrochloric acid on 3 moles of potassium phenolate? What chemical properties of phenol are illustrated by this reaction?

11.26. Write down the equation for the reaction of interaction between potassium phenolate and carbonic acid. What products are obtained in the reaction? What properties of phenol are illustrated by this reaction?

11.27. Why is phenol brominated much easier than benzene? What quantity of tribromophenol can be prepared by the action of the appropriate quantity of bromine on 2 moles of phenol?

62. Aldehydes. Ketones

11.28. Write down the equation of the reaction for preparing (a) formic aldehyde; (b) acetic aldehyde; (c) propionic aldehyde by oxidizing the corresponding alcohol with copper oxide. Calculate for each reaction the quantity of aldehyde that is formed in oxidation of 0.5 mole of alcohol.

11.29. What quantity of ethyl alcohol should be oxidized completely to prepare 0.1 kilomole of acetic aldehyde, if the yield of the process is 98 per cent?

11.30. Ammonia solution of silver oxide is used as a specific reagent for aldehydes. The solution is prepared by adding an aqueous solution of ammonia to a 2 per cent solution of $AgNO_3$. The ammonia solution is prepared by diluting a 25 per cent solution of NH_3 with ten-fold quantity of distilled water. Calculate the quantity of silver nitrate required to prepare 3 kg of its 2 per cent solution.

11.31. What quantity of silver will be liberated by oxidizing 0.5 mole of acetic aldehyde with the appropriate quantity of ammonia solution of silver oxide?

11.32. Write down the equation for the silver mirror reaction for (a) formic aldehyde; (b) acetic aldehyde; (c) propionic aldehyde; (d) butyric aldehyde. Calculate for each case the quantity of acid prepared from 1.2 moles of aldehyde.

11.33. Write down the equation for the reaction of reduction with hydrogen into alcohol of (a) formic aldehyde; (b) acetic aldehyde; (c) propionic aldehyde; (d) butyric aldehyde. Calculate for each case the quantity of hydrogen required to reduce 2 moles of aldehyde.

11.34. The unsaturated aldehyde acrolein can be regarded as a product of displacement of the hydrogen atom in a molecule of ethylene by the aldehyde group:

$$\text{ethylene } CH_2{=}CH_2, \text{ acrolein } CH_2{=}CHCHO$$

Acrolein is the product of oxidation of unsaturated allyl alcohol $CH_2{=}CH{-}CH_2OH$. It is oxidized itself into unsaturated acrylic acid $CH_2{=}CH{-}COOH$.

Write down the equations for the reactions of formation (a) of acrolein from alcohol; (b) of acrylic acid from acrolein.

Use atomic oxygen as the oxidant in both cases.

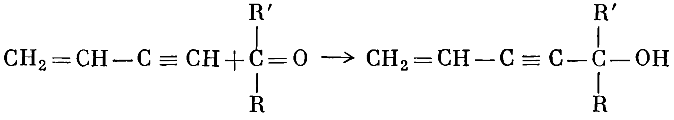
What quantity in grams of acrylic acid can be prepared from 2 moles of acrolein?

11.35. Acetone $(CH_3)_2CO$ is prepared by calcining calcium carbonate:

$$(CH_3COO)_2Ca \longrightarrow (CH_3)_2CO + CaCO_3$$

What quantity of acetone $(CH_3)_2CO$ can be prepared from (a) 2 kilomoles of the salt; (b) 2 kg of the salt containing 2 per cent of admixtures; (c) 79 kg of pure salt if the yield of the product is 98 per cent?

11.36. Carbinol glue is formed by the interaction between vinylacetylene $CH_2{=}CH{-}C{\equiv}CH$ and ketones:



$$CH_2{=}CH{-}C{\equiv}CH + \underset{R}{\overset{R'}{C}}{=}O \longrightarrow CH_2{=}CH{-}C{\equiv}C{-}\underset{R}{\overset{R'}{C}}{-}OH$$

The reaction proceeds in the presence of potassium hydroxide.

Calculate (a) the quantity in grams of vinylacetylene required to prepare 10 moles of carbinol glue by the reaction with acetone; (b) the quantity of carbinol glue that can be prepared from 0.5 mole of vinylacetylene; (c) the quantity of acetone that reacts with 1 kg of vinylacetylene in the preparation of the glue.

CHAPTER TWELVE

CARBOXYLIC ACIDS. ESTERS. FATS

63. Carboxylic Acids

12.1. The general formula of saturated monobasic acids is R—COOH, where R is the hydrocarbon radical. What is the structure of the radical in (a) butyric acid $C_4H_8O_2$; (b) caproic acid $C_6H_{12}O_2$; (c) palmitic acid $C_{16}H_{32}O_2$?

12.2. Consider formic, acetic, propionic, butyric, and stearic acids and answer what is called the acid radical and the acidic group of a carboxylic acid.

12.3. Write down the equations for electrolytic dissociation of (a) formic, acetic, and propionic acids; (b) sodium acetate, calcium acetate.

12.4. Write down the molecular and structural formulas of basic salts formed by acetic acid, aluminium, trivalent iron, and having one hydroxyl in their molecules.

12.5. A mixture of equal volumes of formic and concentrated sulphuric acids is decomposed with heating. The products of the decomposition are water and carbon monoxide. What role does H_2SO_4 play in this reaction?

What quantity in grams of formic acid produces (a) 84 g; (b) 2.5 moles; (c) 44.8 litres (at NTP) of carbon monoxide?

12.6. What quantity in grams of magnesium is required to liberate from formic acid (a) 10 g; (b) 5 moles; (c) 10 litres (at NTP) of hydrogen? What is the other product of the reaction? Write down its structural formula.

12.7. What quantity of formic acid can be neutralized by (a) 20 g of sodium hydroxide; (b) 20 g of a 10 per cent solution of potassium hydroxide?

12.8. What quantity of sodium bicarbonate is required to neutralize 50 g of a 30 per cent solution of formic acid?

12.9. Acetic acid can be prepared by hydration of acetylene in the presence of mercuric salts as catalysts (Kucherov's reaction) with subsequent oxidation of the formed aldehyde by atmospheric oxygen. Write down the reaction equations. What quantity in (a) grams; (b) kilomoles; (c) litres (at NTP) of acetylene is required to prepare 100 kg of acetic acid?

12.10. Write down chemical equations for the following transformations:

$$C \xrightarrow{+CaO} CaC_2 \xrightarrow{+H_2O} CH \equiv CH \xrightarrow{+H_2O} CH_3CHO \xrightarrow{+O_2} CH_3COOH$$

What quantity of coal containing 88 per cent of carbon is required to prepare 100 tons of acetic acid, the yield of the product being 90 per cent?

12.11. Acetic acid is formed during acetic fermentation of alcoholic solutions. Molds propagating on the surface of the liquid promote oxidation of alcohol by atmospheric oxygen through the agency of enzymes which are carriers of oxygen:

$$C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$$

What quantity of acetic acid can be prepared by this method from (a) 100 moles; (b) 460 g of alcohol if the yield is 90 per cent?

12.12. What quantity in grams of a 30 per cent solution of sodium hydroxide is required to neutralize (a) 30 g; (b) 2 moles; (c) 20 g of a 10 per cent solution of acetic acid?

12.13. What quantity in grams of powdered chalk containing 98 per cent of calcium carbonate $CaCO_3$ is required to neutralize 4 moles of acetic acid? What salt is formed in this reaction? Write down its structural formula.

12.14. Calcium acetate is decomposed with heating into calcium carbonate and acetone. Write down the equation of the corresponding reaction and calculate the quantity of acetone that can be prepared from the salt taken in amount of (a) 63 g; (b) 3 moles.

12.15. Large quantities of acetic acid are produced during dry distillation of wood. To separate acetic acid from methyl alcohol and other substances the acid is neutralized with lime and the prepared calcium acetate is then decomposed by hydrochloric or sulphuric acid. Calculate the quantity of (a) slaked lime that is required to neutralize 0.5 ton of acetic acid; (b) hydrochloric acid (density 1.2 g/cc) required to decompose 24 g of calcium acetate; (c) acetic acid which is formed in this process.

12.16. Calcium acetate prepared by neutralization of acetic acid with slaked lime was calcined, as a result of which acetone and chalk were obtained.

Calculate (a) the quantity of calcium acetate that was prepared in the process if the quantity of acetone recovered from it was 29 kg; (b) the quantity of acetic acid which should be neutralized with slaked lime to prepare 1 kg of calcium acetate; (c) the quantity in grams of slaked lime required to prepare from acetic acid 20 g of calcium acetate.

12.17. Write down structural formulas of (a) potassium formiate; (b) calcium acetate; (c) basic ferric acetate containing one hydroxyl in its molecule.

12.18. What ions are present in the solution of (a) zinc acetate; (b) sodium formiate?

12.19. An aqueous solution of soap was acted upon with a 10 per cent sulphuric acid with heating as a result of which 20 g of free stearic acid were liberated. Write down the equation of the corresponding reaction. Calculate the quantity of potassium stearate which reacted with sulphuric acid.

12.20. What quantities in grams of sodium stearate and calcium hydrocarbonate react to form 0.25 mole of calcium stearate? What is the practical importance of this reaction in everyday life?

12.21. Acrylic acid can be prepared by the reaction between acetylene, carbon monoxide and water in the presence of a catalyst. Write down the equation for this reaction and calculate (a) the quantity of acrylic acid that can be prepared from 2 moles of acetylene, 260 g of acetylene; (b) the quantity in units of volume of carbon monoxide required to react with 0.1 mole of acetylene during formation of acrylic acid.

12.22. Benzoic acid (monobasic) is the product of oxidation of benzoic aldehyde C_6H_5CHO. Write down the molecular and structural formulas of (a) benzoic acid; (b) potassium benzoate; (c) benzyl alcohol, the product of reduction of benzoic aldehyde.

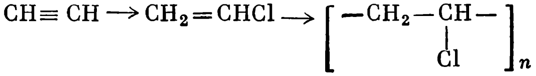
12.23. What quantity of sodium benzoate can be prepared by neutralizing 0.25 mole of benzoic acid by a stoichiometric quantity of sodium hydroxide?

64. Esters. Fats

12.24. Write down the equation for the reaction of preparation of (a) ethyl benzoate; (b) propyl acetate; (c) methyl propionate. What quantity of acid is consumed in each of these reactions during formation of 0.2 mole of ester?

12.25. Vinyl ethyl ether $CH_2{=}CHOC_2H_5$ is used in the manufacture of plastics. Write down the equations for the reactions by which this ether can be produced.

12.26. Write down the equations for the reactions that take place during the following conversions:



$$CH{\equiv}CH \rightarrow CH_2{=}CHCl \rightarrow \left[-CH_2-\underset{\displaystyle Cl}{\underset{|}{CH}}- \right]_n$$

Name the substances in this series.

12.27. What quantity in grams of stearic acid reacts with glycerol to form (a) 89 g; (b) 0.5 mole of tristearin?

12.28. What quantity in kilograms of tripalmitin can be prepared in the reaction of 2 kilomoles of glycerol with the required quantity of palmitic acid?

12.29. What quantity of pure triolein was hydrolyzed if on termination of heating the fat with water (a) 9.2 kg of glycerol; (b) 8.46 kg of oleic acid were prepared? (Assume the hydrolysis to be complete in both cases.)

12.30. Pure tristearin was heated with the required quantity of sodium hydroxide to produce 18.4 kg of glycerol. What quantity of sodium hydroxide took part in the reaction?

12.31. What quantity of glycerol was prepared in the reaction between 10 kg of tripalmitin containing 2 per cent of admixtures and the required quantity of pure potassium hydroxide? (Assume the yield of glycerol to be 96 per cent.)

12.32. What quantity of pure triolein was hydrogenated if (a) 5 tons of pure tristearin; (b) 10 kilomoles of tristearin containing 4 per cent of admixtures were prepared?

65. Laboratory Exercises and Review Problems

12.33. Prove experimentally that formic acid is an aldehyde and an acid at the same time.

12.34. Add dropwise bromine water to 2 ml of oleic acid in a test-tube. The bromine water is decolourized. Why? Write down the equation for the corresponding reaction and the structural formula of dibromostearic acid formed in the process.

12.35. Prepare an insoluble calcium salt from a soap solution. Explain the experiment by the appropriate chemical equation.

12.36. Write down the equations for the following chemical transformations:

(1) $CH_4 \rightarrow CH_3Cl \rightarrow CH_3OH \rightarrow CH_3OK$

(2) $C_2H_6 \rightarrow C_2H_5I \rightarrow C_2H_5OH \rightarrow CH_3CHO \rightarrow CH_3COOH$

(3) $C_6H_6 \rightarrow C_6H_5Cl \rightarrow C_6H_5OH \rightarrow C_6H_5ONa \rightarrow C_6H_5OH$

(4) $C_2H_6 \rightarrow C_2H_5Br \rightarrow C_2H_5OH \rightarrow CH_3COOH \rightarrow CH_3COOC_2H_5$

CHAPTER THIRTEEN

CARBOHYDRATES. NITROCOMPOUNDS

66. Carbohydrates

13.1. What chemical properties of glucose prove its (a) aldehyde; (b) alcoholic nature? Give a detailed answer and illustrate it with the equations of the corresponding reactions.

13.2. What quantity in grams of glucose can be oxidized into gluconic acid by (a) 0.5 mole of silver oxide; (b) 2.32 g of silver oxide?

13.3. What quantity in grams of silver oxide is required to oxidize (a) 60 g; (b) 0.2 mole of glucose into gluconic acid?

13.4. What quantity of silver will be liberated during reduction of (a) 0.2 mole; (b) 4.6 g of silver oxide with the appropriate quantity of glucose?

13.5. What quantity of gluconic acid is formed by oxidation with excess of silver oxide of (a) 90 g; (b) 4 moles of glucose?

13.6. Calculate the percentage composition of the alcohol into which glucose is reduced.

13.7. During alcoholic fermentation of glucose, 230 g of ethyl alcohol were produced. What quantity of carbon dioxide expressed in (a) grams; (b) moles; (c) litres (at NTP) was liberated in the process?

13.8. What quantity in grams of glucose was fermented if (a) 23 g; (b) 6 moles of ethyl alcohol were produced as a result? What quantity in litres of CO_2 (at NTP) was liberated in each particular case?

13.9. Calculate the percentage composition of beet sugar $C_{12}H_{22}O_{11}$.

13.10. Calculate the quantitative ratio of the elements in starch.

67. Nitrocompounds. Amines. Carbamide

13.11. During nitration of 39 g of benzene with the appropriate quantity of nitric acid (a) 61.5 g; (b) 0.5 mole of nitrobenzene were produced. What quantity of nitric acid reacted in each particular case?

13.12. 39 kg of benzene were nitrated into 61.2 kg of nitrobenzene. What is the yield of nitrobenzene in per cent of theory?

13.13. What quantity in grams of nitric acid is required to nitrate (a) 15.6 g; (b) 0.2 mole of benzene into nitrobenzene?

13.14. What quantity in kilograms of benzene reacts with nitric acid to form (a) 369 kg; (b) 0.25 kilomole of nitrobenzene?

13.15. 156 g of benzene reacted with 140 g of nitric acid to form what quantity of nitrobenzene? Which of the starting substances and in what quantity remained in excess?

13.16. What quantity in grams of nitrobenzene can be formed from 234 g of benzene and 189 g of nitric acid, if the yield is 98 per cent?

13.17. What quantity in grams of nitrobenzene can be prepared from 312 g of benzene and the required quantity of nitric acid if the yield is 92 per cent? What quantity in millilitres of nitric acid (density 1.44 g/cc) is required for the purpose?

13.18. 105 g of nitrobenzene were prepared in the laboratory from 78 g of benzene. What is the yield in per cent of theory?

13.19. Chloropicrin CCl_3NO_2 (poison) is prepared by acting with chlorine on an alkaline solution of picric acid. Write down the structural formula of chloropicrin bearing in mind that it can be regarded as trichloronitromethane or as nitrochloroform.

(a) What quantity of chloropicrin can be prepared by acting with a small excess of chlorine on: 458 kg; 4 kilomoles of picric acid?

(b) In the reaction between 22.9 kg of picric acid and the appropriate quantities of chlorine and water, 49 kg of chloropicrin were produced. What is the yield in per cent of theory?

13.20. What quantity in grams of nitrobenzene is required to prepare (a) 0.5 mole; (b) 46.5 g of aniline if the yield is 100 per cent?

13.21. What quantity in grams of hydrogen is required to reduce (a) 24.6 kg; (b) 6 kilomoles of nitrobenzene?

13.22. Calculate the quantity of aniline which is formed from 493 kg of nitrobenzene and 24 g of hydrogen, assuming the yield to be 100 per cent. Which of the starting substances and in what quantity remains in excess?

13.23. What quantity of nitrobenzene is required to prepare 182.28 kg of aniline, which is 98 per cent of theory?

13.24. Calcium cyanamide $CaCN_2$ is a valuable fertilizer which is prepared by acting with nitrogen on hot calcium carbide:

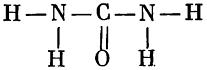
$$CaC_2 + N_2 \longrightarrow CaCN_2 + C$$

Moreover, ammonia can also be produced from calcium cyanamide:

$$CaCN_2 + 3H_2O \longrightarrow CaCO_3 + 2NH_3$$

Calculate (a) the quantity of nitrogen in kilograms, kilomoles, litres (at NTP) that reacts with 128 kg of calcium carbide to prepare the cyanamide; (b) the quantity in tons of commercial calcium carbide containing 4 per cent of admixtures required to prepare 160 tons of calcium cyanamide, if the yield is 100 per cent; (c) the quantity of water that decomposes 40 kg of calcium cyanamide in the production of ammonia.

13.25. Urea (carbamide) $(NH_2)_2CO$ has the structural formula

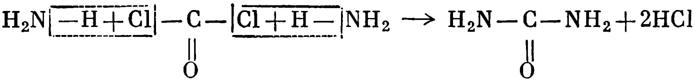


$$H-\underset{H}{\underset{|}{N}}-\underset{O}{\underset{\|}{C}}-\underset{H}{\underset{|}{N}}-H$$

It is the fertilizer richest in nitrogen. Urea is prepared by reacting ammonia with carbon dioxide at high temperature and pressure:

$$2NH_3+CO_2 \rightarrow (NH_2)_2CO+H_2O$$

It can also be synthesized from phosgene $COCl_2$ and ammonia:



$$H_2N\boxed{-H+Cl}-\underset{O}{\underset{\|}{C}}-\boxed{Cl+H-}NH_2 \rightarrow H_2N-\underset{O}{\underset{\|}{C}}-NH_2+2HCl$$

Calculate (a) the percentage content of nitrogen in urea; (b) the quantity of CO_2 expressed in grams, moles and litres (at NTP) required to react with 18 g of ammonia; (c) the quantity of NH_3 expressed in grams, moles and litres (at NTP) which reacts with 2.2 kilomoles of CO_2; (d) the quantity of urea formed from 33 kg of phosgene. What quantity of ammonia is consumed in the process?

68. Laboratory Exercises and Review Problems

13.26. Prove the presence of carbon in (a) glucose; (b) saccharose; (c) starch.

13.27. Determine experimentally which of the two test-tubes contains a solution of glucose.

13.28. Prove experimentally that wheat bread contains starch.

13.29. Hydrofluoric acid is used in wine- and beer-making to control bacteria inducing acetic, lactic, and other undesirable fermentation. It is sufficient to add 10 g of a 30 per cent hydrofluoric acid to 100 litres of the liquor to kill the bacteria. The bacteria producing alcoholic fermentation persist. Calculate the concentration of hydrogen fluoride in the fermentation liquid in grams per litre.

13.30. Nitrate benzene into nitrobenzene.

13.31. Prove whether or not protein is contained in the solution under question.

13.32. Coagulate protein by three methods.

13.33. Benzene, formaldehyde, and acetic acid are available. Identify each substance (a) by its physical properties; (b) by specific reactions.

CHAPTER FOURTEEN

HIGH-MOLECULAR SYNTHETIC SUBSTANCES (POLYMERS)

69. Monomers

14.1. Butadiene (divinyl) C_4H_6 ($CH_2=CH-CH=CH_2$) can be prepared by passing ethyl alcohol vapour over special catalysts (with heating):

$$2C_2H_5OH \rightarrow C_4H_6 + 2H_2O + H_2$$

What quantity of butadiene can be prepared from ethyl alcohol taken in amount of (a) 184 kg; (b) 8 kilomoles? Assume the yield of the product to be 96 per cent of theory.

14.2. What quantity of ethyl alcohol is required to prepare (a) 162 g; (b) 20 moles of butadiene? Assume the yield to be 100 per cent.

14.3. Butadiene (divinyl) used in the manufacture of synthetic rubber is at the present time prepared not only from ethyl alcohol but also from gases obtained in petroleum refining, namely from butane C_4H_{10} and butylene $CH_2=CH-CH_2-CH_3$. Write down the equations for the reactions of dehydrogenation of (a) butane into butylene; (b) butylene into divinyl.

What quantity of butane forms 392 g of butylene in the dehydrogenation process? What quantity of butadiene is prepared by dehydrogenation of 168 g of butylene?

14.4. What quantity in kilograms of butadiene can be prepared from 220 kg of butylene containing 2 per cent of admixtures, if the yield of the process is 100 per cent?

70. Laboratory Exercises

14.5. Cement two plates of plexiglass by using acetone.

14.6. Demonstrate the high stretching properties of molten capron.

APPENDICES

Table 1

Solubility of Salts and Bases in Water

	K	Na	Ba	Ca	Mg	Al	Cr III	Fe II	Fe III	Mn II	Zn	Ag	Hg II	Cu II	Pb II
OH	s	s	s	p	p	i	i	i	i	i	i	—	—	i	i
Cl	s	s	s	s	s	s	s	s	s	s	s	i	s	s	p
S	s	s	s	s	—	—	—	i	i	i	i	i	i	i	i
SO_3	s	s	i	i	i	—	—	i	—	i	i	i	i	i	i
SO_4	s	s	i	p	s	s	s	s	s	s	s	p	—	s	i
PO_4	s	s	i	i	i	i	i	i	i	i	i	i	i	i	i
CO_3	s	s	i	i	i	—	—	i	—	i	i	i	—	—	i
SiO_3	s	s	i	i	i	i	i	—	i	i	i	—	—	—	i
NO_3	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
$H_3C_2O_2$	s	s	s	s	s	p	—	s	—	s	s	s	s	s	s

Roman numerals designate the valence of the metals. The letter' 's' denotes 'soluble in water', the letter 'p' means 'poorly soluble, and the letter 'i' stands for 'insoluble'. A dash in the box means that the salt either does not exist at all or is decomposed by water.

Table 2

Density of Hydrochloric Acid of Various Concentration at 15°C

Density g/cc	Concentration %	Density g/cc	Concentration %	Density g/cc	Concentration %
1.000	0.16	1.075	15.16	1.145	28.61
1.005	1.15	1.080	16.15	1.150	29.57
1.010	2.14	1.085	17.13	1.152	29.95
1.015	3.12	1.090	18.11	1.155	30.55
1.020	4.13	1.095	19.06	1.160	31.52
1.025	5.15	1.100	20.01	1.163	32.10
1.030	6.15	1.105	20.97	1.165	32.49
1.035	7.15	1.110	21.92	1.170	33.46
1.040	8.10	1.115	22.86	1.171	33.65
1.045	9.16	1.120	23.82	1.175	34.42
1.050	10.17	1.125	24.78	1.180	35.39
1.055	11.18	1.130	25.75	1.185	36.31
1.060	12.19	1.135	26.70	1.190	37.23
1.065	13.19	1.140	27.66	1.195	38.16
1.070	14.17	1.142	28.14	1.200	39.11

Table 3

Density of Nitric Acid of Various Concentration at 15°C

Density g/cc	%	Density g/cc	%	Density g/cc	%
1.000	0.10	1.200	32.36	1.430	72.17
1.005	1.00	1.210	33.82	1.440	74.68
1.010	1.90	1.220	35.28	1.450	77.28
1.015	2.80	1.230	36.78	1.460	79.93
1.020	3.70	1.240	38.29	1.465	81.42
1.030	5.50	1.250	30.82	1.470	82.90
1.040	7.26	1.260	41.34	1.475	84.45
1.050	8.99	1.270	42.87	1.480	86.05
1.060	10.68	1.280	44.41	1.485	87.70
1.070	12.33	1.290	45.95	1.490	89.60
1.080	13.95	1.300	47.49	1.495	91.60
1.090	15.53	1.310	49.07	1.500	94.09
1.100	17.11	1.320	50.71	1.501	94.60
1.110	18.67	1.330	52.37	1.502	95.08
1.120	20.23	1.340	54.07	1.503	95.55
1.130	21.77	1.350	55.79	1.504	96.00
1.140	23.31	1.360	57.57	1.505	96.39
1.150	24.84	1.370	59.39	1.506	96.76
1.160	26.36	1.380	61.27	1.507	97.13
1.170	27.88	1.390	63.23	1.508	97.50
1.175	28.63	1.400	65.30	1.509	97.84
1.180	29.38	1.410	67.50	1.510	98.12
1.190	30.88	1.420	69.80	1.520	99.67

Table 4

Density of Sulphuric Acid of Various Concentration at 15°C

Density g/cc	%	Density g/cc	%	Density g/cc	%	Density g/cc	%	Density g/cc	%
1.000	0.09	1.185	25.40	1.370	46.94	1.555	64.67	1.740	80.68
1.005	0.95	1.190	26.04	1.375	47.47	1.560	65.20	1.745	81.12
1.010	1.57	1.195	26.68	1.380	48.00	1.565	65.65	1.750	81.56
1.015	2.30	1.200	27.32	1.385	48.53	1.570	66.09	1.755	82.00
1.020	3.03	1.205	27.95	1.390	49.06	1.575	66.53	1.760	82.44
1.025	3.76	1.210	28.58	1.395	49.59	1.580	66.95	1.765	83.01
1.030	4.49	1.215	29.21	1.400	50.11	1.585	67.40	1.770	83.51
1.035	5.23	1.220	29.84	1.405	50.63	1.590	67.83	1.775	84.02
1.040	5.96	1.225	30.48	1.410	51.15	1.595	68.26	1.780	84.50
1.045	6.67	1.230	31.11	1.415	51.66	1.600	68.70	1.785	85.10
1.050	7.37	1.235	31.70	1.420	52.15	1.605	69.13	1.790	85.70
1.055	8.07	1.240	32.28	1.425	52.63	1.610	69.56	1.795	86.30
1.060	8.77	1.245	32.86	1.430	53.11	1.615	70.00	1.800	86.92
1.065	9.47	1.250	33.43	1.435	53.59	1.620	70.42	1.805	87.60
1.070	10.19	1.255	34.00	1.440	54.07	1.625	70.85	1.810	88.30
1.075	10.90	1.260	34.57	1.445	54.55	1.630	71.27	1.815	89.16
1.080	11.60	1.265	35.14	1.450	55.03	1.635	71.70	1.820	90.05

1.085	12.30	1.270	35.71	1.455	55.50	1.640	72.12	1.825	91.00
1.090	12.99	1.275	36.29	1.460	55.97	1.645	72.55	1.830	92.10
1.095	13.67	1.280	36.87	1.465	56.43	1.650	72.96	1.831	92.43
1.100	14.35	1.285	37.45	1.470	56.90	1.655	73.40	1.832	92.70
1.105	15.03	1.290	38.03	1.475	57.37	1.660	73.81	1.833	92.97
1.110	15.71	1.295	38.61	1.480	57.83	1.665	74.24	1.834	93.25
1.115	16.36	1.300	39.19	1.485	58.28	1.670	74.66	1.835	93.56
1.120	17.01	1.305	39.77	1.490	58.74	1.675	75.08	1.836	93.80
1.125	17.66	1.310	40.35	1.495	59.22	1.680	75.50	1.837	94.25
1.130	18.31	1.315	40.93	1.500	59.70	1.685	75.94	1.838	94.60
1.135	18.96	1.320	41.50	1.505	60.18	1.690	76.48	1.839	95.00
1.140	19.61	1.325	42.08	1.510	60.65	1.695	76.76	1.840	95.60
1.145	20.26	1.330	42.66	1.515	61.12	1.700	77.17	1.8405	95.95
1.150	20.91	1.335	43.20	1.520	61.59	1.705	77.60	1.8410	96.38
1.155	21.55	1.340	43.74	1.525	62.06	1.710	78.04	1.8415	97.35
1.160	22.19	1.345	44.28	1.530	62.53	1.715	78.48		
1.165	22.83	1.350	44.82	1.535	63.00	1.720	78.92		
1.170	23.47	1.355	45.35	1.540	63.43	1.725	79.36		
1.175	24.12	1.360	45.88	1.545	63.85	1.730	79.80		
1.180	24.76	1.365	46.41	1.550	64.26	1.735	80.24		

Tablo 5

Density of Aqueous Solutions of Some Alkalis at 18°C

%	KOH	NaOH	NH_3	%	KOH	NaOH	NH_3
4	1.033	1.046	0.983	34	1.334	1.374	0.889
6	1.048	1.069	0.973	36	1.358	1.395	0.884
8	1.065	1.092	0.967	38	1.384	1.416	—
10	1.082	1.115	0.960	40	1.411	1.437	—
12	1.100	1.137	0.958	42	1.437	1.458	—
14	1.118	1.159	0.946	44	1.460	1.478	—
16	1.137	1.181	0.939	46	1.485	1.499	—
18	1.156	1.203	0.932	48	1.511	1.519	—
20	1.176	1.225	0.926	50	1.538	1.540	—
22	1.196	1.247	0.919	52	1.564	1.560	—
24	1.217	1.268	0.913	54	1.590	1.580	—
26	1.240	1.289	0.908	56	1.616	1.601	—
28	1.263	1.310	0.903	58	—	1.622	—
30	1.286	1.332	0.898	60	—	1.643	—
32	1.310	1.352	0.898				

Atomic Weights of Most Important Chemical Elements (rounded)

Aluminium	Al	27	Lead	Pb	207
Antimony	Sb	122	Magnesium	Mg	24
Argon	Ar	40	Manganese	Mn	55
Arsenic	As	75	Mercury	Hg	201
Barium	Ba	137	Molybdenum	Mo	96
Bismuth	Bi	209	Neon	Ne	20
Boron	B	11	Nickel	Ni	59
Bromine	Br	80	Nitrogen	N	14
Cadmium	Cd	112	Oxygen	O	16
Calcium	Ca	40	Phosphorus	P	31
Carbon	C	12	Platinum	Pt	195
Chlorine	Cl	35.5	Potassium	K	39
Chromium	Cr	52	Silicon	Si	28
Copper	Cu	64	Silver	Ag	108
Fluorine	F	19	Sodium	Na	23
Gold	Au	197	Sulphur	S	32
Helium	He	4	Tin	Sn	119
Hydrogen	H	1	Tungsten	W	184
Iodine	I	127	Vanadium	V	51
Iron	Fe	56	Zinc	Zn	65

ANSWERS TO PROBLEMS

CHAPTER ONE

1.1. (a) 36 g; (c) 240 g; (d) 8 g. **1.2.** (d) 2 g-atoms; (f) 0.25 g-atom. **1.4.** (b) 20 moles; (c) 0.1 mole. **1.5.** (c) 2 moles. **1.7.** (b) 10 kilomoles. **1.10.** (c) 1 mole of KOH is 14 times heavier. **1.11.** (b) 8 and 23. **1.13.** (b) About 1.6 and 2.2 (rounded). **1.16.** (b) 8.2 g and 7.7 g (rounded). **1.17.** (a) 2.8 litres and 8 litres. **1.18.** (b) 1.5 g (rounded). **1.20.** (c) 6 : 1. **1.21.** (a) 2.7%; 2.74%; 25%. **1.23.** Fe_3O_4. **1.24.** 78.2%. **1.26.** (a) 5.2%, 30%, 55.8%; (j) 40%, 12%, 48%. **1.27.** (a) 8 g; (b) 16 g. **1.31.** (a) 3 moles; (c) 0.1 mole. **1.44.** (a) 5 kg-atoms (rounded). **1.49.** (a) 6.36 g. **1.53.** (a) 120 g, 18 g. **1.55.** (a) 0.2 g, 0.1 mole, 2.24 litres; (b) 4 g; 2 moles; 44.8 litres. **1.58.** 2.8 kg or 50 moles. **1.60.** (a) 19.7 g; (b) 1.588 kg. **1.61.** 10.304 tons. **1.62.** (a) 217 g. **1.66.** (c) 2.220 kg. **1.69.** (1) (a) 0.98 g; (1) (b) 49 g

CHAPTER TWO

2.2. (a) 8.88 kg; (b) 532.66 kg; (c) 110.97 kg; (d) 0.793 kg. **2.3.** (a) 3,000 moles; (b) 213 kg; (c) 67,200 litres. **2.4.** (a) 6.5 g; (b) 0.1 mole. **2.5.** (a) 23.67 g; (b) 0.33 mole; (c) 7.47 litres. **2.6.** 1.7749 kg. **2.7.** 2 kg. **2.8.** (a) 174 g; (b) 304.5 g; (c) 696 g. **2.9.** (a) 1.25 moles; (b) 88.75 g; (c) 28 litres. **2.10.** 106.5 litres; 33.6 litres. **2.11.** (a) 10 moles; (b) 0.01 kilomole; (c) 1.225 kg. **2.12.** (a) 147 g; (b) 2.94 g; (c) 29.4 g. **2.17.** (a) 26.1 g. **2.18.** (b) 61 g. **2.20.** About 2.7 g. **2.23.** 383.56 m^3. **2.24.** (a) 2 g of H_2 in excess; (b) 1 mole of H_2 in excess; (c) 0.52 litre of Cl_2 in excess. **2.25.** 0.717 ton. **2.26.** 8.49 kg of HCl; 301 kg of Cl_2. **2.27.** (a) 0.33 kg of HCl; 0.67 litre of H_2O. **2.28.** 0.79 kg of H_2; 27.23 kg of Cl_2. **2.32.** 2.9%. **2.33.** 92.3%. **2.37.** 95%. **2.38.** 1.155 tons. **2.39.** 92.9%. **2.40.** 3.090 tons. **2.53.** 143.2 g; 250.5 g. **2.57.** 98%. **2.61.** (a) 480 g. **2.75.** 3 g of $AgNO_3$; 10.1 g of KNO_3. **2.77.** 355 g. **2.78.** No; 35.5 g are required. **2.81.** 127 kg. **2.82.** 12.7 kg. **2.86.** 72 g. **2.90.** 93.57%. **2.92.** 99.34%. **2.104.** (a) 0.168 g

CHAPTER THREE

3.1. (a) 69 g; (b) 117 g. **3.2.** (a) 78 g; (b) 92 g; (c) 117 g; (d) 920 g; (e) 15.6 g. **3.3.** 164 g; 125 g. **3.4.** Cryolite. **3.5.** KCl. **3.6.** (a) 24.24%; (b) 11.34%; (e) 23.26%. **3.7.** (a) 40 g; (b) 1.6 kg. **3.10.** (a) 4.87 g; (b) 10.99 g. **3.12.** 53 g of Na_2CO_3

CHAPTER FOUR

4.8. (a) 50.45%; (d) 53.33%. **4.9.** (f) 3.25%. **4.22.** (a) 13; (b) 12; (c) 34. **4.28.** (b) 16; (d) 13. **4.29.** (a) 23; (b) 28; (d) 16. **4.30.** 14. **4.31**; (a) 6; (e) 12. **4.36.** Ca^{2+}; S^{2-}; Fe^{2+}; Fe^{3+}; O^{2-}

CHAPTER FIVE

5.2. 350 g. **5.4.** About 40 g. **5.11.** 90 g. **5.13.** (c) 75 g of salt, 425 g of water; (f) 264 kg of salt, 1,936 litres of water. **5.15.** 0.12 kg; 0.24 kg; 5.64 litres. **5.17.** (b) 20%. **5.18.** 2.44%. **5.20.** (e) 4.8 g. **5.22.** 32 kg; 31.6 litres. **5.24.** (c) 1 kg. **5.26.** 17.45%. **5.29.** (a) 6.42 g; (b) 2.58 g; 6.3 g. **5.31.** (a) 14.67 g; (b) 17.30. **5.33.** (c) About 21.5%. **5.34.** (b) 645 ml of solution and 1.355 litres of water. **5.37.** (b) 1 : 10. **5.38.** (c) 4 parts of water per one part of NaOH by weight. **5.40.** (a) 2 : 5; (b) 5 : 2; (c) 1 : 3. **5.41.** (c) 2 : 1. **5.43.** (b) 1 : 2. **5.47.** (a) 3 : 2. **5.53.** 5 : 2. **5.54.** 1 : 1. **5.61.** (b) 49 g, 1.951 litres. **5.62.** (d) 82.08 g. **5.63.** (a) 100 ml; (b) 10 ml; (c) 10 litres. **5.64.** (a) 2 litres; (b) 0.5 litre; (c) 0.25 litre. **5.67.** 0.5 litre. **5.70.** (c) 3 m. **5.73.** (b) 3.6 *M* (rounded). **5.74.** (a) 9.17 *M*; (b) 20.28 *M*. **5.75.** 0.33 ml. **5.76.** 18.7 (rounded). **5.77.** 29.75. **5.80.** 0.28 (rounded). **5.81.** (a) 81 and 49. **5.82.** (b) 47 and 31. **5.83.** (c) 54.67 and 63.5. **5.84.** (f) 1.12 g. **5.85.** (d) 4.9 g. **5.87** (a) 0.1 *N*. **5.88.** 50 ml. **5.91.** (b) 40 ml. **5.93.** (a) 0.004; (e) 0.0071. **5.94.** (b) 3 *N*

CHAPTER SIX

6.1. (b) 2.66 moles. **6.2.** (c) 4.48 litres. **6.3.** (a) 2.14 g. **6.4.** (a) 24; (b) 1.66 (rounded). **6.5.** (a) 0.47 (rounded); (c) 5.6 litres. **6.6.** (b) 294 g. **6.7.** (b) 84.5 g. **6.9.** 16.66 g. **6.13.** 78.75%. **6.15.** (c) 15.17 g. **6.16.** (a) 5.87 g; (b) 6.4 g; (c) 12.5 g; (d) 17.88 g. **6.17.** (a) 9.44 kg; (b) 0.28 mole; (c) 6.2 litres. **6.18.** (1) 0.1 mole, 2.28 litres; (2) 1.8 g; 3.2 g. **6.19.** (a) 0.9 g; (b) 1.5 g. **6.20.** 1.44 g. **6.21.** (a) 9%; (b) 5.63%. **6.22.** 17.75%. **6.24.** (a) 48 g; (b) 1.5 moles; (c) 33.6 litres. **6.25.** (a) 2.86 g; (b) 10 g; (c) 12.8 g. **6.26.** (a) 2.8 litres; (b) 67.2 litres; (c) 350 litres. **6.27.** 696 g. **6.28.** (a) 960 g; (b) 2 moles; (c) 48 g. **6.29.** 18 kg. **6.30.** 2.264 kg. **6.32.** 10.5%. **6.33.** (a) 32 g, 8 g of Na_2SO_3 in excess; (c) 18.3 g of gas and 35 g of Na_2SO_3 in excess. **6.37.** 93.79%. **6.38.** 97.78%. **6.39.** 97.5%. **6.40.** 23.05 tons. **6.43.** 1,380 kg. **6.44.** 98.99%. **6.45.** 1.136 tons. **6.46.** Oleum is heated; 0.2 ton. **6.47.** (a) 116.5 g; (b) 58.25 g; (c) 11.65 g

CHAPTER SEVEN

7.1. (a) 53.5 g; (b) 10 moles; (c) 214 g; (d) 856 g; (e) 428 g; (f) 215 g. **7.2.** 33.84 kg. **7.5.** 1 : 1; 2.388 kg. **7.6.** (a) 70 g, 73 g; (b) six moles. **7.7.** (a) 8.5 g and 31.5 g; (b) three moles. **7.8.** 68 g of NH_3; 140 g of NH_4OH; 196 g of H_2SO_4. **7.9.** (a) 17 g and 31 g; 5 moles and 2.5 moles; (b) 35 g and 31 g; 5 moles and 2.5 moles. **7.10.** (a) 102 g and 196 g;

(b) 18 moles and 6 moles. **7.11.** 107 g and 1 g of NH_3. **7.12.** 26.75 g and 0.2 litre of HCl. **7.13.** 240 g and 1 g of NH_3. **7.14.** 157.4 g and 0.25 g of HNO_3. **7.15.** 77.42 kg. **7.16.** (a) 316 g; (b) 632 g. **7.20.** (d) 44.8 litres, 54 g. **7.21.** (a) 138 g. **7.26.** 31.5 g. **7.28.** 27.2 g; 12.6 g. **7.29.** 3.706 tons. **7.32.** (a) 21.33 g and 6.67 g of NO; (b) 32 g and 46 g of NO_2. **7.36.** 50.5 g. **7.41.** 10.6 kg. **7.42.** (a) 16.08 kg; (b) 15.6 kg; (c) 14.4 kg

CHAPTER EIGHT

8.1. (a) 1.2 g; (b) 1.2 g. **8.2.** 875 kg. **8.3.** 44.8 litres. **8.4.** (c) 60 kg. **8.5.** (a) 0.88 ton. **8.6.** 1.120 kg. **8.7.** 52 tons. **8.8.** 98.76%. **8.10.** 98 kg of $CaCO_3$; 17.64 litres of H_2O; 108.78 kg of $CaCl_2$. **8.12.** 16 g. **8.13.** (b) 18.5 g. **8.14.** (a) 2.24 litres and 0.1 mole of $Ca(OH)_2$ in excess. **8.16.** 1.06 litres; 96%. **8.17.** (b) 17.6 of CO_2, 65.4 g of HCl. **8.18.** 6.9 g; 1.66 g of HCl in excess. **8.19.** (a) 690 g. **8.20.** (c) 11 g. **8.22.** (a) 0.1 mole of $COCl_2$ and 0.5 mole of Cl_2; (b) 49.5 g of $COCl_2$ and 2 g of CO; (c) 1.2 litres of $COCl_2$ and 10 litres of CO

CHAPTER NINE

9.12. (a) 1.2 g, 13.44 litres; (b) 1.5 g, 16.8 litres; (c) 4 g, 44.8 litres. **9.13.** (a) 8 kilomoles. **9.14.** (a) 3.25 g. **9.15.** (a) 124.44 g; (b) 622.22 g. **9.16.** 6.8 g. **9.19.** (a) 20 g; (b) 800 g. **9.20.** (a) 43.8 kg; (b) 87.638 tons. **9.21.** (a) 1.56 g; 0.84 g of NaOH. **9.22.** (a) 80 g; (b) 190 kg. **9.24.** (a) 200 g; (b) 160 g. **9.25.** (a) 1.05 tons; (d) 0.277 kg. **9.26.** (a) 54 g; (b) 180 g; (c) 180 litres. **9.27.** (a) 1,215.7 kg. **9.32.** (a) 50 g; (b) 0.5 kg. **9.38.** (a) 116.5 kg; (b) 466 kg. **9.40.** (a) 2 g of O_2 in excess; (b) 1.5 moles of O_2 in excess; (c) 3.6 litres of O_2 more are required. **9.41.** (a) 25.2 kg of Al, 81.8 kg of Fe_3O_4. **9.42.** 11.2 g. **9.43.** 2.7 g. **9.44.** 9.63 kg of Cr; 1.63 kg of Cr_2O_3. **9.45.** 0.1 kg of MnO_2. **9.49.** 5.4 g of Al and 37.78 ml of H_2SO_4. **9.50.** 1.52 g. **9.51.** 78 g. **9.52.** 4 moles. **9. 53.** 40 g. **9.54.** (a) 1.96 tons; (b) 1.63 tons. **9.56.** (b) 238 g. **9.57.** (a) 6.3 g. **9.61.** (a) 7.1 ml. **9.62.** 4 g-atoms. **9.63.** (b) 4 kg-atoms. **9.64.** 4 kg-atoms. **9.65.** 6 moles. **9.67.** 2.94 g. **9.69.** 302 g. **9.71.** 37.8 g. **9.83.** 595.4 tons. **9.84.** 3.102 tons. **9.85.** 4.64 g. **9.87.** 1.133 tons. **9.88.** 33.6%. **9.89.** (a) 80 kg; (b) 80 kg. **9.90.** 22.78 g. **9.92.** 94 g; 46 g of NO_2. **9.93.** (a) 32 g; 4.48 litres of SO_2. **9.94.** 10 g. **9.95.** 0.3 g of $Cu(NO_3)_2$; 2.45 g of $Cu(OH)_2$. **9.96.** 9.8 g; 0.8 g of KOH in excess. **9.98.** (a) 106 g; (b) 80 g. **9.100.** 6.4 g or 2.24 litres at NTP. **9.101.** 0.25 mole or 58 g. **9.102.** 17 g. **9.103.** 37.6 g. **9.104.** 23.5 g; 1.4 g of KI. **9.106.** (a) 6.5 tons; (c) 3.25 g. **9.107.** (a) 239.2 kg. **9.108.** 754.94 kg. **9.110.** 573.3 kg. **9.112.** (b) 119.75 kg. **9.113.** (a) (1) 871 ml; (b) 320.3 g; 5.2 g of H_2SO_4 in excess. **9.114.** (a) 6.77 g. **9.115.** (b) 278 ml. **9.146.** 13.6 g. **9.147.** 1.78 g; 3.07 g of KOH in excess, **9.148.** 7.35 g and 2.3 g of NaOH. **9.149.** 1.6 g. **9.151.** 1.93 g

CHAPTER TEN

10.1. (a) 48 g; (b) 3 moles; (c) 67.2 litres. **10.2** 15.68 g. **10.3.** (a) 8; (b) 0.55; (c) 1.4 litres; (2) 0.71 g. **10.4.** NO. **10.5.** (a) 320 g; (b) 20 moles; (c) 40 litres. **10.9.** 0.75 kg. **10.10.** (a) 252.5 kg; (b) 606 g. **10.11.**

(a) 926.125 kg. **10.12.** 426 kg. **10.13.** (a) 18 g; (b) 17.28 g. **10.14.** (a) 11.5 g; (b) 23 g. **10.16.** (b) 8 g or 5.6 litres. **10.17.** (a) 1,870 litres; (b) 3,200 litres. **10.18.** (b) 1.320 kg, 30 moles, 672 litres. **10.19.** (b) 1.034. **10.23.** 88 g. **10.26.** (a) 1,980 litres; (b) 9,900 litres. **10.27.** 10,400 litres. **10.30.** (a) 10 moles; (c) 2.3 g. **10.33.** 150 litres. **10.34.** 396 kg. **10.38.** (b) 34.78 kg; (c) 3.106 kg. **10.39.** (a) 5 m^3; (b) 25 m^3. **10.42.** (a) 234 g. **10.43.** (a) 268.8 litres; (b) 1.344 m^3. **10.44.** (a) 430.8 litres; (b) 2.154 m^3. **10.46.** (b) 582 kg. **10.48.** (b) 900 g. **10.49.** 314 g and 5 g. **10.50.** 95.54%

CHAPTER ELEVEN

11.4. 537.8 g. **11.5.** (a) 310.8 g; (b) 148 g. **11.11.** (a) 2.300 kg; (b) 9.200 kg; (c) 10.26 g. **11.12.** 92 g. **11.13.** 16 g. **11.14.** (a) 202.4 kg. (c) 1.27 kg. **11.19.** (a) 96 g; (b) 128 g; (c) 1.600 kg. **11.20.** (a) 14.3 kg; (b) 72 g. **11.22.** 11.6 g. **11.24.** 120 g of NaOH, 1 mole of C_6H_5OH; **11.31.** 108 g. **11.32.** (b) 106.6 g

CHAPTER TWELVE

12.5. (c) 92 g. **12.6.** (c) 10.7 g. **12.7.** (b) 1.6 g. **12.8.** 27.4 g. **12.11.** (b) 540 g. **12.14.** (a) 23.1 g. **12.15.** (a) 308.33 g. **12.19.** 22.6 g. **12.21.** (a) (1) 144 g; (b) 2.24 litres. **12.24.** (c) 14.8 g. **12.28.** 1.612 tons. **12.29.** (b) 8.84 kg. **12.30.** 24 kg. **12.32.** 8.4864 tons

CHAPTER THIRTEEN

13.2. (a) 90 g; (b) 1.8 g. **13.3.** (a) 77.33 g; (b) 46.4. **13.4.** (a) 43.2 g; (b) 4.28 g. **13.5.** (a) 220 g; (b) 5 moles; (c) 112 litres. **13.8.** (a) 45 g; (b) 540 g. **13.9.** 42% of C, 6% of H and 52% of O. **13.10.** 7.2 : 1 : 8. **13.11.** (a) 31.5 g; (b) 0.5 mole or 31.5 g. **13.12.** 33.51%. **13.13.** (a) 12.6 g; (b) 12.6 g. **13.14.** (a) 234 kg; (b) 19.5 kg. **13.15.** 246 g; 14 g of HNO_3. **13.16.** 361.62 g. **13.17.** 452.64 g; 234.3 ml. **13.19.** (a) 987 kg, 12 kilomoles; (b) 99.29%. **13.20.** (a) 61.5 g; (b) 61.5 g. **13.21.** (a) 1.2 kg. **13.22.** 372 g; 1 g of $C_6H_5NO_2$. **13.23.** 246 kg. **13.24.** (a) 56 kg, 2 kilomoles; (b) 133.3 tons; (c) 27 kg. **13.25.** (c) 22 g, 74.8 kg, 4.4 kilomoles, 98,560 m^3; (d) 20 kg, 10.3 kg. **13.29.** 0.03 g/litre

CHAPTER FOURTEEN

14.1. (a) 103.68 kg; (b) 207.36 kg. **14.2.** (a) 276 kg; (b) 1.840 kg. **14.3.** 406 g; 162 g. **14.4.** 207.9 kg

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