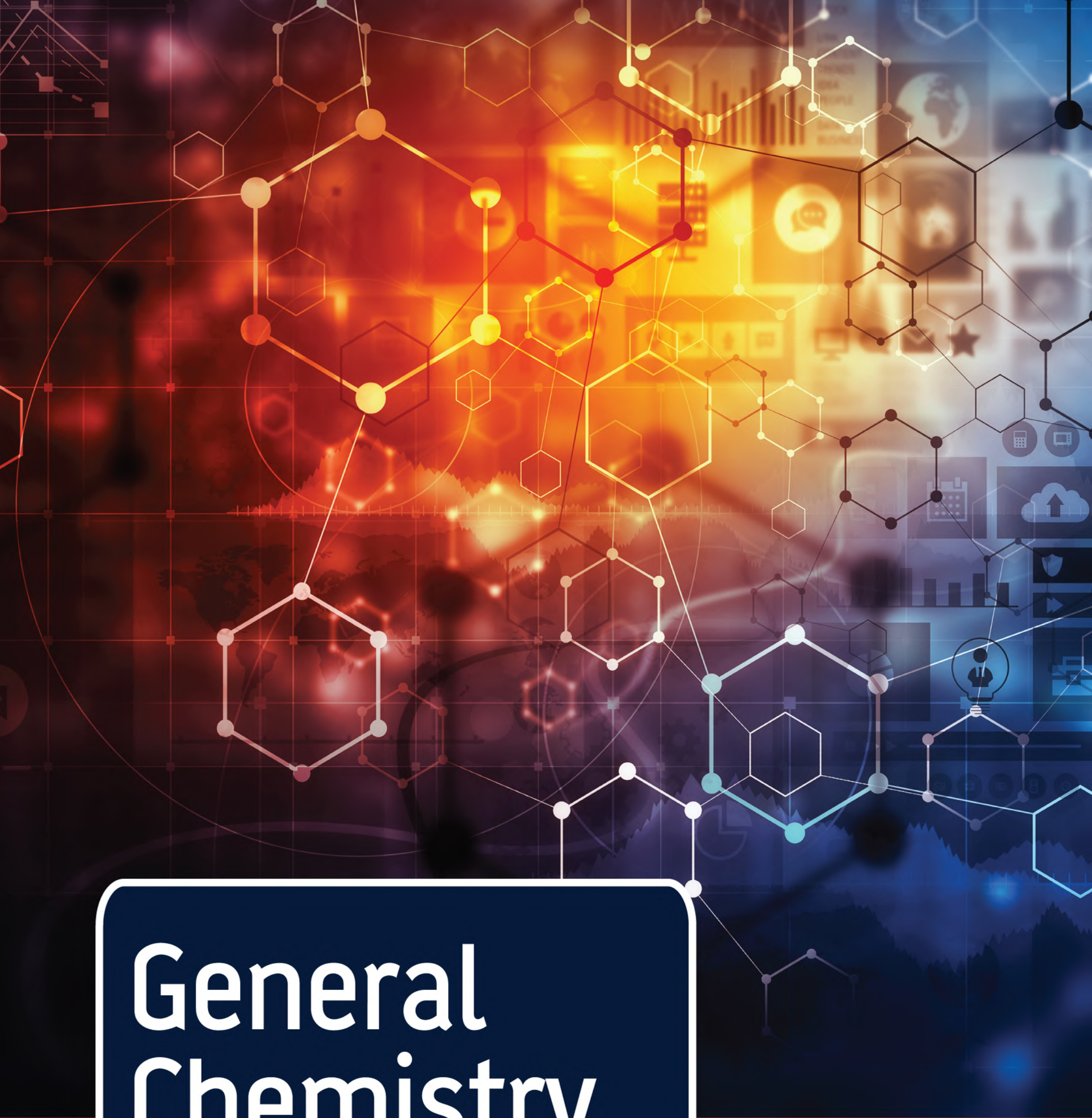

General Chemistry

Rainer Roldan Fiscal

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LIST OF ABBREVIATIONS

C	cathode
C2H5OH	ethanol
C3H6O	acetone
C6H14	hexane
C6H6	benzene
C7H16	heptane
C7H8	toluene
CH3OH	methanol
CHCl3	chloroform
CNIC	Commission on Nomenclature of Inorganic Chemistry
CS2	carbon disulfide
IMFs	intermolecular forces
IPK	international prototype kilogram
K	Kelvin
KE	kinetic energies
NaOH	sodium hydroxide
NH3	ammonia
OH–	hydroxide ion
SI	System of Units

PREFACE

Chemistry has been a subject that has helped in the evolution of humans in a manner that very few of the other subjects have. Chemistry finds its applications across verticals such as food, medical, manufacturing, and other crucial aspects on which the humans depend for existence.

Chemistry as a subject is taught to students so that they know about the basics of chemistry in case they encounter any regular problem of reference to the chemicals, say in case of salts in a medicine.

At higher levels of the study and teaching of chemistry, other information comes in like the kinds in which chemistry is divided, the reactions and the product that they give, the chemistry of physical occurrences of chemicals and compounds and other such areas of concern.

This book brings the focus of the readers to the topics that cover almost all aspects related to chemistry so that they get a complete idea of chemistry in a short composition. The book introduces the general form of chemistry to them, which might be valuable in explaining all the basics of chemistry to the readers in an appropriate way.

The book explains the readers about the relation that chemistry holds with other sciences. The readers should know the reason behind any subject they want to read and the relevance it holds in the physical world. This will help them have an interest in the subject and feel more connected with it.

The book also discusses the different kinds of chemistry and what each kind deals in. All the elements in chemistry are depicted in a tabular form that is commonly known as the periodic tables. The placing of each element that is found on earth has been done very thoughtfully so as to organize all the elements in several categories and classify them to study about their physical or chemical occurrence.

The book explains the periodic table in detail to the readers so that they are absolutely clear with the basics of the periodic table. It also informs the readers about the development of the periodic table and the history it holds with regard to the manner in which the elements have had been added to the table.

There is a special significance that solutions hold in chemistry. It explains the various states in which the solutions can be found and the concept of equilibrium in the solutions. The readers are informed about the energy that is produced in the formation of a solution.

The book also focuses on the various parameters that decide the solubility of solutions and the bonds that are formed in order to form a solution. It also explains the meaning of ideal and non-ideal solutions and the relevance they hold.

The book further moves to introduce the topics of salts, bases, and acids. The readers are explained about each of them. The book explains the readers about their occurrence, formation, importance, uses, and all other aspects related to them. It also informs them about some of the most commonly used compounds and what they are according to the classification, so that readers get a first-hand experience of the relevance of all three kinds.

The readers are informed about the process of bonding in chemistry. The book informs them about the different kinds of bonds that exist between various elements in a compound and explains them about the formation of all the kinds of bonds. The book also tells them about the significance of each kind of bond.

The book moves further to discuss the process of electrolysis and informs the readers about various ways in which it can be done and can prove beneficial to the chemical evolution. This it tells the readers about the process of extraction of ions and other such processes.

The book then elaborates on the various units of measurement in the subject of chemistry. It focuses on the SI units and the various conventional and traditional units of measurement, their inter-conversion, and their readability and the manner in which they can be interpreted.

CHAPTER

1

INTRODUCTION TO CHEMISTRY

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- The definition of chemistry
- Various applications of chemistry
- Stoichiometry: elementary atomic theory and chemical kinetics
- Different branches of chemistry

KEYWORDS

- Organic Chemistry
- Stoichiometry
- Inorganic Chemistry
- Physical Chemistry
- Analytical Chemistry
- Green Chemistry
- Biochemistry
- Immunochemistry

1.1. WHAT IS CHEMISTRY?

The scientific study of matter (anything that occupies space and has mass), its features and interactions with energy and other matter is called chemistry. Chemistry can also define as the science that involve the systematic study of properties, composition, various elementary forms of matter, and activity of inorganic and organic substances. Science is the identification, experimental investigation, observation, description and theoretical explanation of natural phenomena.”

Figure 1.1: Chemistry: the study of matter.

Source: http://www.thebluediamondgallery.com/tablet/c/chemistry.html

1.1.1. Relation of Chemistry with Other Sciences

It is important to note that chemistry is a science that indicates its methodologies are reproducible and systematic and its theories are examined using scientific methods. The scientists who study chemistry are called chemists.

Chemists are not only responsible for examining the interactions between the substances but also are responsible for studying the properties of matter and their composition. Chemistry is closely connected to biology and physics. Chemistry as well as physics both falls under the category of physical sciences. In fact, according to some scripts the definition of physics and chemistry is entirely the same. Like in other sciences, for the study of chemistry also mathematics plays a vital role.

1.1.2. Need to Study Chemistry

Many people search ways to avoid chemistry or are scared it or have chemistry phobia. This is because it involves equations and math.

However, it is essential for an individual to know the basic and general principles involved in **chemistry**, whether you have to take a chemistry class for a grade or not. Chemistry is at the heart of understanding everyday materials and processes.

The study of chemistry helps the people to understand the various phenomena that are going on around them. It explain some processes such as the reason behind the change in color of the leaves in the season of fall, the appearance of various kinds of plants, the preparation process of cheese, the composition of soap and the main reason behind why it is used to clean things. All these things can be explained by the application of chemistry.

Chemistry is the scientific discipline involved with elements and compounds composed of atoms, molecules and ions: their composition, structure, properties, behavior and the changes they undergo during a reaction with other substances.

Having acquaintance with the subject of chemistry can enable people to read and understand the text written on the bottles regarding the use of substances in the product. The knowledge of chemistry can help the people in identifying whether some information given about a particular product is true or it is some scam that the advertisers are committing.

It enables them to take smart decision on the actuality of a product being as effective as the advertisers of a product claim it to work and will even modify the way the people expect the products to work. Chemistry can go on to make a person a good cook or a chef.

If the person knows about the way the reactions take place while the food is being cooked, they may be able to bake in a better manner or may even be able to alter the texture of food and its supplements according to the way they want.

The knowledge of the various chemicals can help the people to be secure when they are handling some product at their homes. The familiarity with chemistry will enable them to know about the chemicals that can be harmful to them if they come in some kind of contact with them. So, the people would know how to handle a product that contains a particular chemical in it.

Chemistry can help the people acquire some good reasoning skills as its study that involves solving a lot of problems that come in its way and tries to give reason for a process to occur.

Hence, it helps the people to find the reason behind some events that may be taking place simultaneously in the world, like the rise in the prices of petroleum products, recalling of some products by a company, the scenario of pollution, the innovations taking place in the technologies and the environment and so forth.

The study of chemistry equips the students and others with the knowledge that they may use to find the suitable career paths for themselves. There are several jobs in the industry that require the knowledge of chemistry and the industries may include anything from food industry, transportation, homemaking, art, retail stores and others.

Last but not the least, chemistry has numerous ways to amaze the people with the reactions and other processes such as things glowing in dark, change of states or formation of bubbles and fountains.

1.2. APPLICATIONS OF CHEMISTRY IN DAY-TO-DAY LIFE

Have you ever wondered why chemistry is so important? Why do we study chemistry?
All the things surrounding us, including us, are made up of chemicals. Everything we see, taste, smell, touch and hear is inclusive of chemicals (matter) and chemistry. Seeing, touching, hearing and tasting all involve intricate series of chemical reactions and interactions in our body.

Most of the changes we see around us in the world occur as a result of chemical reactions. Chemistry is not confined to just laboratories and beakers but is all around us. The more we know the chemistry, the better we know our world. Chemistry is observed in every aspect of life. Some examples from our daily life are listed below:

Sky appears blue

Color of an object is seen as a result of the light that it reflects. Sun is source of white light. It comprises of all the wavelengths. When this white light coming from the sun falls on an object, some of the wavelengths get reflected and some are otherwise absorbed. The sky's color is based on the phenomena called **Rayleigh scattering** which says that the particles which are much smaller than its wavelength scatter light.

This effect is especially strong when light passes through gases.

Rayleigh scattering is the phenomena of scattering of light particles majorly by the molecules of gas (sometimes also by solid and liquid).

- Ice floats on water: The density of ice is quite less than water. This is because of it hallow structure. The heavier water displaces the lighter ice, so ice floats on top.
- Working of sunscreen: Sunscreen combines inorganic and organic chemicals to sieve the light coming from the sun in order to reduce the amount of light that reaches the deeper layers of the skin. The reflective particles in sunscreen generally comprises of zinc oxide or titanium oxide.
- Food is cooked faster in a pressure cooker: The lid of a pressure cooker is more elaborated that helps in sealing the pot completely. When water is heated, it comes to a boil and turns into steam, which cannot escape. Therefore, the steam remains inside the cooker and starts developing pressure. As a result of increased pressure, temperature also increases much higher as compared to normal conditions, thus enhancing the rate of cooking.
- Chemistry of love: In a relationship, chemistry is involved at the bottom of every step. When one falls in love, the brain undergoes some changes and some specific chemical compounds

are released. Love is driven by these hormones: vasopressin, oxytocin, endorphins.

- Coffee helps in keeping awake: Because of the presence of chemical called adenosine, in our brain. Coffee helps to keep awake. When sleep is signaled, it binds itself to specific receptors and decreases the activity of nerve cell.

1.2.1. Vegetable Is Colored

- Vegetables are colorful: Most of the fruits and vegetables are strongly colored. This is due to the presence of a special kind of chemical compound called carotenoids. A region called chromophore is present in these compounds. The function of chromophore is to absorbs and give off specific wavelengths of light, producing the same color that is perceived by us.
- Working of soaps: Soap is made up of a certain type of molecule which consists of two parts, namely a ‘head’ and a ‘tail.’ The part head is water loving called hydrophilic and the tail part is water hating called hydrophobic. Now, on adding the soap to water, the hydrophilic head goes into the water whereas the long hydrophobic chains of the molecules join the particles of oil/dirt. This results in the formation of an emulsion of oil in water. This means that the

oil particles become suspended in the water and are liberated from the cloth. With the rinsing, the emulsion is taken away.

- Tears role down our eyes while chopping onions: Onion contains sulfur in the cells. Their breakdown after the chopping of onions results in making us cry. Basically, the sulfur mixes with the moisture present in surroundings and causes irritation in the eyes.
- Cooking involves chemistry: Cooking food is applied chemistry, as the recipes are basically chemical reactions. Some examples of chemistry in action are boiling an egg, baking a cake or bread, etc.
- Digestion: After the cooked food is eaten, this is to be digested. Digestion becomes a set of chemical reactions in order to break down the complex molecules into simpler ones which can easily be absorbed by the body and brought to use.
- Metabolism: A lot more chemistry is involved in the working of cells and the various functions performed by the organs and furthermore, how the absorbed food is providing energy. Biochemical processes of metabolism (catabolism and anabolism) and homeostasis govern health and illness. It is not important to know the details of each of the processes, but one should have the basic knowledge

to understand why, like why do we need to breathe oxygen or the purpose served by molecules, such as insulin and estrogen.

- Chemistry in drugs and supplements: Drugs and supplements are a matter of chemistry. Knowing how chemicals are named can help you decipher labels, not only on a bottle of pills, but also a box of breakfast cereal. You can learn what types of molecules are related to make the best choices for yourself and your family.
- Advanced materials: Many developments in aerospace and **automotive engineering** depend upon enhanced materials like various types of ceramics, the basis of materials research and engineering is chemistry.
- Environment: Chemistry played a vital role so as to understand the major reason behind the beginning of the hole in the ozone layer and also marks a significant role in understanding the environmental impact of the materials that are produced and the procedures to purify them to be environmentally safe.
- Electronics: Chemistry plays an important role in many electronics' fabrication and packaging methods and one day might help in expanding the trend toward faster and cheaper electronics by "molecular electronics," where every single molecule is used

Automotive engineering is a combination of mechanical, electrical and materials science.

as electronic components.

- Foundation of molecular biology: The foundation of molecular biology is chemistry and biochemistry just like the foundation of chemistry is mathematics and physics. The research work in the field of molecular biology is vital in order to improve the quality of life by understanding the human health that is dependent on the development in chemistry and biochemistry.
- Plastics: Plastics and other polymers have become successful in improving our lives in many ways. Chemistry an important role in developing commercial polymers and in understanding their environmental impact and how to dispose them of safely and responsibly.

Everything single thing we see around us is made up of molecules. There are specific types of molecules, which combine in such a fashion that they might cause health risks. If one is aware of the basics of chemistry then the formation of poison by mixing of household products can be avoided.

Understanding chemistry or any science means learning the scientific method. This is a process of asking questions about the world and finding answers that extends beyond science. It can be used to reach logical conclusions, based on evidence.

1.3. GENERAL CHEMISTRY

General chemistry deals with various topics like conservation of energy and mass, periodic table and periodicity, stoichiometry, elementary atomic theory, electrochemistry, chemical kinetics, chemical equilibriums, chemical bonding, acid-base chemistry, gas laws, etc.

1.3.1. Stoichiometry

The study of elements in the quantitative aspect which involves chemical change in a reaction and the concentration of reactants and products form its basis, which are used and produced in the reaction.

1.3.2. Elementary Atomic Theory

Atomic theory defines the structure of atoms from ancient times, including the introduction of atomic structure and subatomic particles like protons, neutrons and electrons that were described on the basis of the experiments like alpha scattering experiment and Bohr model of atomic structure.

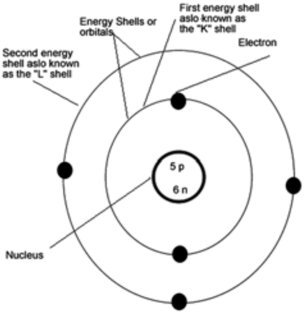

Figure 1.2: The Bohr-Rutherford Atomic Model.

Source: https://www.flickr.com/photos/mrspugliano/5351051650

1.3.3. Periodic Table and Periodicity

Atomic number is the number of protons, and therefore also the total positive charge, in the atomic nucleus.

The term periodicity is referred to as the study of elements and their arrangement in the periodic table. *Atomic number* of the element forms the basis of this property.

1.3.4. Gas Laws

It involves the study of behavior of gas molecules under standard conditions of pressure and temperature. It includes Boyle's law, Charles' law, Gay-Lussac's law, combined gas law, and ideal gas law.

1.3.5. Chemical Kinetics

It deals with the rate of the chemical reactions and path of the chemical reaction. It also includes formation of intermediates during the course of reactions and variables involved in the reactions and products.

1.3.6. Acid-Base Chemistry

It is the branch of chemistry, which talks about the behavior of chemical substances and its nature or reaction towards acids and bases.

1.3.7. Electrochemistry

The study of chemical processes which deals with the electron flow in the chemical reactions using cathode, anode, and salt bridges.

1.3.8. Chemical Equilibria

Equilibria deal with the equilibrium of reaction, which consists of both forward and backward reactions, rate, and the equilibrium constants.

1.4. BRANCHES OF CHEMISTRY

The science involving the study of the composition and structure of matter and chemical reactions that are held responsible for the properties of matter and change of state is termed as chemistry. It is the science of crystals, atoms, molecules and other aggregates of matter and the chemical processes that change entropy levels and energy and also their structure and composition.

Inorganic chemistry deals with the synthesis and behavior of inorganic and organometallic compounds.

Chemistry has been subdivided into distinct disciplines that deal with specific branches of chemistry. There are five major branches of chemistry, namely **inorganic chemistry**, physical chemistry, analytical chemistry, organic chemistry, and biochemistry.

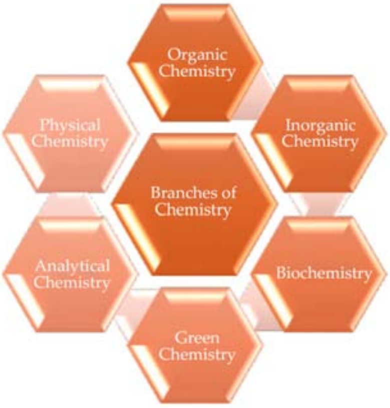

Figure 1.3: Branches of Chemistry.

1.4.1. Organic Chemistry

It is a branch of chemistry that includes studies of chemical compounds which comprises of element carbon and carbon-hydrogen bonds (C-H). Chemists who are specialized in organic chemistry are known as organic chemists. Their researches are mainly based on the properties, types of reaction a compound undergo and the structure.

Through this knowledge they are capable enough to recognize and classify the different naturally occurring organic compounds and also create organic compounds with desired functions and properties. This branch of chemistry includes the study of organic matter. This branch of chemistry deals with the study of composition, structure and chemical properties of organic compounds. This branch also includes the chemical reactions which are used in the formation of organic chemical compounds.

Organic chemistry resides in the heart of many industries such as agrichemicals, pharmaceutical, cosmetics, fuel, dyestuffs, plastic, coatings industries, detergent and rubber.

1.4.2. Inorganic Chemistry

This branch of chemistry deals with the properties and reactions of all chemical compounds which do not contain the carbon-hydrogen bonds (C-H). Thus, it can be stated that inorganic chemistry is the study of chemical compounds that are not organic. The inorganic compounds are generally the non-living matter or the minerals found in the earth’s crust.

This branch of chemistry relates to the behavior, structure and composition of inorganic compounds. Carbonates, oxides and sulfides form the important classes of inorganic compounds.

Industrial inorganic chemistry includes the branch of applied science for example the manufacture of fertilizers, whereas descriptive inorganic chemistry deals with the classification of compounds based on their properties. The role of metals in biology is studied under the branch of **bioinorganic chemistry**.

Bioinorganic chemistry is a field that examines the role of metals in biology. Bioinorganic chemistry includes the study of both natural phenomena such as the behavior of metalloproteins as well as artificially introduced metals, including those that are non-essential, in medicine and toxicology.

1.4.3. Physical Chemistry

This branch of chemistry includes the study of physical properties of chemical compounds using concepts and laws of physics like for example, statistical mechanics, time, motion, quantum chemistry, force, energy and dynamics.

A chemical compound comprises of various physical properties such as surface tension in liquids, electrical conductivity, boiling point, pressure, tensile strength, color, viscosity, plasticity, volume, melting point and solubility.

With the help of mathematical formulas and models, the chemists specialized in physical chemistry (physical chemists) are capable enough to quantify the physical properties of chemical substances. They are also able to find out the effect of certain phenomena on the physical properties of chemical substances.

This branch of chemistry applies the theories of physics to atoms and subatomic particles. When **physical chemistry** is applied to the chemical interaction between atoms and subatomic particles, the study is known as quantum mechanics.

It is a relatively vast field that deals with intermolecular forces, rates of chemical reactions as well the conductivity of different materials. The application of quantum mechanics to chemical systems is dealt with in the field of quantum chemistry.

Physical chemistry is the study of macroscopic, atomic, subatomic, and particulate phenomena in chemical systems in terms of the principles, practices, and concepts of physics such as motion, energy, force, time, thermodynamics, quantum chemistry, statistical mechanics, analytical dynamics and chemical equilibrium.

1.4.4. Analytical Chemistry

This branch of chemistry includes the identification, separation and quantification of chemical substances (analytes) in a given sample. In general terms, the studies of analytical chemistry allow the chemists to find out the chemical substances that could be present in a given material.

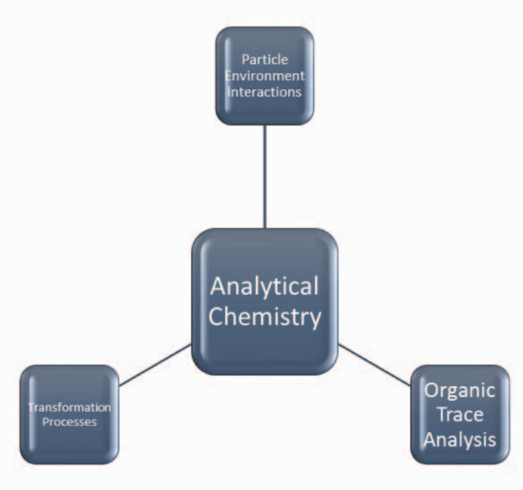

Figure 1.4: Analytical Chemistry.

Two aspects are involved in analytical chemistry namely, quantitative analysis and qualitative analysis. Quantitative analysis includes the determination of the concentration or the amount of the substance in the sample whereas the qualitative analysis comprises of the processes which are carried out in order to determine a chemical substance in a given sample.

In order to carry out the quantification and identification of a chemical substances to maximum degree of accuracy, a number of physical and chemical methods have been developed.

Chemical substance is any material that has a definite chemical composition.

Purely chemical methods were developed in the nineteenth century and are called as classical methods (also known as wet chemistry methods). Chemical or classical methods comprises the use of chemical substances of known composition to recognize the analyte (chemical substance being examined). Analytes can also be determined by color, odor, melting point or boiling point.

Classical methods used by quantitative analyses includes **titrimetry**, in which the concentration of the analyte is identified by the volume of a reagent needed to completely react with it, and gravimetry, in which the presence of the amount of the analyte is recognized by the mass of product derived from a chemical reaction including the chemical sample and a suitable chemical compound.

Classical methods are quite accurate and precise; however, they have few serious shortcomings. They need quantity of the sample in appropriate amount and the concentration of the analyte present in the sample should be less than 0.1%. They also need trained chemists in order to conduct them out, who might need to prepare the standard solutions to be used.

Physical methods for quantifying and identifying chemical substances are based on the strength of the electrical signals generated by the analyte at an electrode or on the amount of light emitted or absorbed by the analyte, physical methods are also known as the instrumental methods. This is because in order to find out the physical quantities of the analytes, they are dependent on the use of machines.

Titrimetry refers to a group of methods of quantitative analysis in which an analyte is determined basing on its stoichiometric reaction with a reagent of established concentration introduced to a sample gradually, in small portions until the analyte is consumed quantitatively.

Classical methods are more accurate or precise than physical methods, but the physical methods need little sample and can identify concentration of analytes that are less than 0.1% of the sample. The physical methods produce results at a faster pace in comparison to classical methods. Because of the inventions of more powerful analytical machines, the classical methods are gradually being replaced by the instrumental methods.

Analytical chemistry has wide applications in clinical analysis, environmental analysis, material analysis, forensics, and bioanalysis.

Analytical chemistry is a very important branch of chemistry that includes the analysis of chemical properties of man-made and natural materials. The study does not restrict itself to any particular type of chemical compounds. Analytical chemistry primarily deals with the study of chemicals present in a substance, in what quantity they are present, and how they define its chemical properties. Instrumental analysis is a prominent part of modern analytical chemistry.

1.4.5. Biochemistry

Biochemistry is the branch of chemistry that involves the study of the composition, structure and chemical reactions of chemical components of the living systems (insects, microorganisms, viruses, mammals and plants) in order to know why and how chemical reactions occur in them.

Biochemistry combines biology with inorganic, physical and organic chemistry. It deals with problems including the chemical basis of heredity, the fundamental changes that take place in diseases and how living things obtain energy from foods.

Biochemistry has applications on wide scale in dentistry, medicine, agriculture, veterinary medicine and food science. It has application in fields such as pharmacology, physiology, clinical chemistry and microbiology where biochemists (scientists that study biochemistry) might study the mechanism of functions of organ or apply chemical concepts, the mechanism of a drug activity, research viral activities, procedures and techniques to examine the treatment and diagnosis of disease and evaluation of health.

This branch deals with the behavior and structure of the components of cells and the chemical processes in living beings. The large and complex biomolecules are generally composed of identical units that repeat. The complex molecules are known as polymers and the basic units they are composed of, are known as monomers. Biochemistry deals with the study of cellular constituents like lipids, carbohydrates, proteins and nucleic acids as also the chemical processes that occur in cells.

1.4.6. Green Chemistry

In order to reduce the production or use of harmful substances green chemistry brings the concept of applying chemical research and engineering to design products and devise processes. The intentions of green chemistry are to obtain solutions scientifically to the environmental problems.

Figure 1.5: Green Chemistry.

1.5. OTHER BRANCHES

Some other branches of chemistry are:

Agricultural Chemistry

It is the study of biochemistry and chemistry pertaining to processing of raw products into foods, removal of environmental pollution, agricultural production, and monitoring the quality of the environment.

Atmospheric Chemistry

The branch of atmospheric science that involves the studies of the chemistry of the Earth's atmosphere and that of other planets.

Click Chemistry

This branch of chemistry deals with the production of substances by combining small units. The term was given by the American chemist Karl Barry Sharpless.

Environmental Chemistry

It deals with the study of biochemical and chemical processes that occur in the natural environment. Environmental chemistry includes the study of the aquatic environment, soil and the chemical conditions of the atmosphere. It also deals with the study of the interactions occurring between the natural environment like water, soil or air and the chemical species. It also comprises of the study of the effects of various activities of human on the environment.

Immunochemistry

This branch of chemistry involves the study of reactions and components of the immune system.

Industrial Chemistry

It deals with the testing, development, design, and prototyping of new industrial products.

Mathematical Chemistry

It applies mathematics to chemistry.

Mechanochemistry

Mechanochemistry is also called as mechanical chemistry. It combines chemical and mechanical phenomena on a molecular level. Mechanochemistry involves the study of the mechanical energy needed for a chemical reaction or change to take place in a substance. It also involves the transfer of chemical to mechanical energy.

Mechanochemistry is the coupling of mechanical and chemical phenomena on a molecular scale and includes mechanical breakage, chemical behaviour of mechanically stressed solids (e.g., stress-corrosion cracking or enhanced oxidation), tribology, polymer degradation under shear, cavitation-related phenomena (e.g., sonochemistry and sonoluminescence), shock wave chemistry and physics, and even the burgeoning field of molecular machines.

Medicinal Chemistry

It is the application of chemistry for medical or medicinal purposes.

Nuclear Chemistry

Nuclear chemistry is one of the most popular and very important branches of chemistry. It involves radioactivity. It talks about the study of chemical processes and nuclear properties in radioactive substances.

This branch of chemistry also deals with the study of instruments used for conducting nuclear processes. This branch of chemistry involves the manufacture and use of radioactive materials, radiotherapy and effects of the absorption of radiation.

Radiochemistry

Radiochemistry deals with the study of radioactive materials. The reactions and the properties of the non-radioactive isotopes are studied using the radioactive isotopes. This branch utilizes the principles of **radioactivity** in order to study chemical reactions.

Petrochemistry

This branch of chemistry involves the study of the conversion of natural gas and crude oil into products which are of great use to industries.

Radioactivity refers to the particles which are emitted from nuclei as a result of nuclear instability.

Phytochemistry

It deals with the study of phytochemicals. Phytochemicals are chemical substances obtained from plants. It is a branch of chemistry as well as botany.

Sonochemistry

It studies the collapse and rise of microbubbles in liquids to which an ultrasonic field is applied. This branch of chemistry deals with the study to determine how ultrasonic fields affect the chemical activity in liquids.

Supramolecular Chemistry

Supramolecular chemistry is that branch of chemistry that is generally known as the chemistry beyond the molecules. This means that it involves the study of non-covalent bonds. This branch of chemistry includes the study of relatively reversible and weak non-covalent intermolecular interactions. Some of the forces studies under this branch are electrostatic effects, Van der Waals forces and hydrogen bonds.

Theoretical Chemistry

It deals with the study to determine explanations for physical and chemical observations. It applies laws in physics to explain and predict chemical phenomena. Computational chemistry uses computer simulation in order to solve chemical problems. It uses methods of theoretical chemistry in computer programs that are designed to calculate structures of molecules and chemical properties.

Wet Chemistry

The branch of chemistry that deals with the study of substances in the liquid phase, it is also called bench chemistry.

Carbon atom is considered to be special and unique because it can bond with other **carbon atoms** to an almost unlimited degree.

Bioorganic Chemistry

Bioorganic chemistry involves biological processes that include the combination of organic chemistry and biochemistry.

Organometallic Chemistry

Organometallic chemistry deals with the study of compounds with minimum one bond between a **carbon atom** and a metal.

Polymer Chemistry

Polymer chemistry deals with the chemical properties and chemical synthesis of polymers. In order to study biological systems, biophysical chemistry applies the concept of physical chemistry and physics.

Physical Organic Chemistry

Physical Organic Chemistry is the study of how the structure of organic molecules of a substance is associated with its reactivity.

Astrochemistry

Astrochemistry combines astronomy with chemistry and studies the reactions of chemical elements in the universe and their interactions with radiation. It also deals with the study of chemical substances in stars and the interstellar space.

Cosmochemistry

Cosmochemistry deals with the study of **chemical composition** of matter in the universe.

Chemical composition is the arrangement, type, and ratio of atoms in molecules of chemical substances.

Electrochemistry

Electrochemistry studies the interaction between electrical energy and chemical change.

Chemical Thermodynamics

Chemical Thermodynamics studies how heat and work are related to chemical reactions or with physical changes of state. Rates of chemical processes are studied in the field of **chemical kinetics**.

Femtochemistry

Femtochemistry is a field of physical chemistry that studies chemical reactions that occur in very short time periods.

Spectrochemistry

Spectochemistry applies spectroscopy to various fields of chemistry.

Pure Chemistry

Pure chemistry involves the study of the pure theory of chemistry conducted with the intention of gaining knowledge of chemical substances.

Applied Chemistry

Applied chemistry includes a research work undertaken with a specific goal or towards devising a practical application in chemistry. Thus, it can be considered as a link between chemistry and chemical engineering.

REVIEW QUESTIONS

1. Define chemistry.
2. Why it is required to study chemistry?
3. Describe the applications of chemistry in day-to-day life.
4. Why ice floats on water?
5. What is the main reason behind rolling down of tears while chopping onions?
6. Define the process of metabolism.
7. Explain stoichiometry.
8. Discuss the elementary atomic theory.
9. Describe the significance of green chemistry.
10. What are the impacts of industrial chemistry on the environment?

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CHAPTER

2

PERIODIC TABLE AND ATOMIC PROPERTIES

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- The atomic properties of elements
- Classification of elements: Dobereiner's law of triads, Newlands' law of octaves, periodic table
- Structure, features and positions of the metals and non-metals
- Atomic and ionic size of the elements
- The concept of electronegativity

KEYWORDS

- Periodic Table
- Newlands' Law of Octaves
- Mendeleev's Periodic Table
- Metalloids
- Non-Metals
- Dobereiner's Law of Triads
- Atomic Properties
- Atomic Size
- Ionic Size
- Ionization Enthalpy

2.1. AN INTRODUCTION TO ATOMIC PROPERTIES

All of us have observed that a vegetable vendor keeps the heap of onions separately from the heap of potatoes. But, let's imagine for instance, that both of them are kept together and say one has to purchase 1 ½ kg of onions. What will happen? One would consume plenty of time, first time will be taken to sort them and then weigh them.

When you have different type of material substances, it is advisable to keep them classified in order to get an easy access and quick use. It is next to impossible to mix clothes with cosmetics or eatables or books. Classification makes sure that the eatables are kept in kitchen and books on the study table or shelf or rack and cosmetics should be on the dressing table. Managers, storekeepers, business houses, information technology experts and scientists, shopkeepers and administrators keep their materials duly classified.

A similar challenge was faced by the chemists when they were mend to hold a huge number of elements. A major set of problems was faced by them during the study of the chemical and physical properties and maintain a systematic record. Finally, the task of classification of elements was successful because of the remarkable work of the chemists. This chapter talks about the need, genesis of classification and periodic trends in chemical and physical properties of elements.

2.2. EARLY ATTEMPTS MADE TO CLASSIFY ELEMENTS

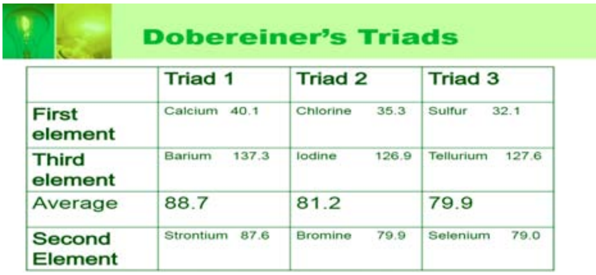
Numbers of attempts were made for the classification of elements from the time of the discovery of metals or may be earlier than that. Various attempts by various chemists are given below.

2.2.1. Dobereiner's Law of Triads

In 1817, Johann Wolfgang Dobereiner, a German chemist gave law of triads, stating that the atomic mass of the middle element of the triad (set of three elements with similar chemical properties) is roughly equal to the arithmetic mean of the atomic masses of the other two elements. For example, the atomic mass of lithium is 7 and the atomic mass of potassium is 39. The average mass of lithium and potassium gives the **atomic mass** of sodium, i.e., 23.

However, the law failed. All the known elements could not be arranged in the form of triads. Thus, the law was not efficient for elements with extremely high or extremely low atomic masses. For example, the atomic mass of fluorine is 19 and the atomic mass of bromine is 80. The average atomic mass of fluorine and bromine is 49.5 whereas the atomic mass of chlorine is 35.5, which is quite dissimilar to the average atomic mass. Hence, the law failed.

Atomic mass is a characteristic of an atom that is a measure of its size.



Dobereiner's Triads

	Triad 1	Triad 2	Triad 3
First element	Calcium 40.1	Chlorine 35.3	Sulfur 32.1
Third element	Barium 137.3	Iodine 126.9	Tellurium 127.6
Average	88.7	81.2	79.9
Second Element	Strontium 87.6	Bromine 79.9	Selenium 79.0

Figure 2.1: Dobereiner's Triad.

Source: https://slideplayer.com/slide/8389419/

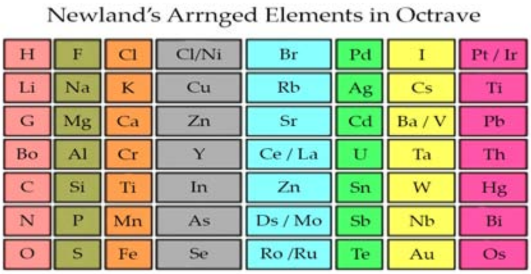
2.2.2. Newlands' Law of Octaves

In 1863, John Alexander Reina Newlands arranged the known elements in the increasing order of their atomic masses and developed a system of classification of elements and titled it as Law of Octaves. The law stated, when the elements are arranged in the increasing order of their atomic masses, the properties of every eighth element are same as to the first. He compared his law to the octaves found in music. Thus, named as law of octaves.

However, the law failed due to some limitations. Firstly, the law was applicable only up to calcium and could apply to the higher atomic masses. Also, in order to follow his law, Newland placed two elements in the same slot. Thus, Newland's attempt to classify elements also failed.

Periodicity: ***Re-occurrence of properties after regular intervals.***

More significant results were obtained when Julius Lothar Meyer's work reflecting the periodicity was found to be based on physical properties of the elements. He clearly showed that certain properties showed a periodic trend.



Newland's Arrnged Elements in Octrave

H	F	Cl	Cl/Ni	Br	Pd	I	Pt / Ir
Li	Na	K	Cu	Rb	Ag	Cs	Ti
G	Mg	Ca	Zn	Sr	Cd	Ba / V	Pb
Bo	Al	Cr	Y	Ce / La	U	Ta	Th
C	Si	Ti	In	Zn	Sn	W	Hg
N	P	Mn	As	Ds / Mo	Sb	Nb	Bi
O	S	Fe	Se	Ro /Ru	Te	Au	Os

Figure 2.2: Newlands' Law of Octaves.

Source: https://www.tes.com/lessons/K6t-POL46PNUH9A/organization-of-periodic-chart

2.2.3. Mendeleev's Periodic Table

One of the most significant contributors to the early development of the periodic table was Dmitri Ivanovich Mendeleev, a Russian chemist. A lot of attempts were made to develop the periodic table, but the most significant one was developed by Mendeleev.

In 1869, after the failure of the Newlands' Law of Octaves, Mendeleev periodic table came into the scene.

The periodic table developed by Mendeleev, consisted of elements organized on the basis of their atomic masses (the fundamental property of an element) and chemical properties.

During the time of Mendeleev's research and studies, only 63 elements were discovered so far. After studying the properties of all the elements, Mendeleev came to the conclusion that the properties of the elements were linked to the fundamental property, atomic mass in a periodic way. Elements were arranged in such a manner by him, that the elements with identical properties were kept together into the same vertical columns of the periodic table.

Since most of the elements react with hydrogen and oxygen, thus Mendeleev choose hydrides and oxides as the basis of criteria for categorization. Since 63 elements were known at that time, thus Mendeleev collected 63 cards in order to write the properties of elements on each card. Accordingly, he then chooses the elements bearing similar properties and pinned them on the wall. He found that the elements were organized in the increasing order of the atomic mass and there was re-occurrence of properties periodically in elements.

According to this studies and observations, he gave a periodic law that says:

"the properties of elements are the periodic function of their atomic masses."

Mendeleev named the vertical columns as groups and the horizontal rows as periods in his periodic table.

- **Advantages of Mendeleev's Periodic Table**
    - Mendeleev left some gaps in his periodic table, as he believed that elements discovered in future could be placed there. He also predicted the existence of some elements and named them by prefixing a Sanskrit numeral, Eka (meaning one).
- **Drawbacks of Mendeleev's Periodic Table**
    - There was no fixed position given to hydrogen in Mendeleev's periodic table. This is because hydrogen resembles both alkali metals as well as the **halogen** family (Group 17).
    - The order of the increase in atomic mass was not followed in some cases. For example, cobalt in spite of being heavier was placed before nickel.
    - Isotopes were not given any position in Mendeleev periodic table. Isotopes are the atoms of same elements having same atomic number but different mass number. Men-

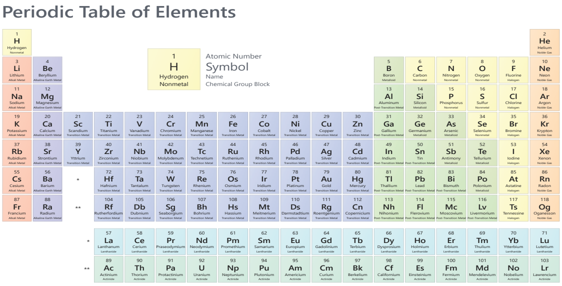
Halogen is any of the six nonmetallic elements that constitute Group 17 (Group VIIa) of the periodic table.

deleev's periodic table was based on the fundamental property, atomic mass. Thus, isotopes should be placed. But he failed to do so.

2.3. MODERN PERIODIC TABLE

Year 1913, the discovery of the most important property of an element called atomic number by a team whose leader was Henry Moseley. The periodic table whose basis is atomic number is called the modern periodic table. Moseley arranged all the known elements in the ascending order of their atomic number and came to the conclusion that the properties of elements are the periodic functions of their atomic numbers.

Hence, he gave the Modern periodic law, which states that the properties of the elements are the periodic functions of their atomic number.



Periodic Table of Elements

1 H Hydrogen Nonmetal
Atomic Number
Symbol
Name
Chemical Group Block

1 H Hydrogen Nonmetal																	2 He Helium Noble Gas
3 Li Lithium Alkali Metal	4 Be Beryllium Alkaline Earth Metal											5 B Boron Metalloid	6 C Carbon Nonmetal	7 N Nitrogen Nonmetal	8 O Oxygen Nonmetal	9 F Fluorine Halogen	10 Ne Neon Noble Gas
11 Na Sodium Alkali Metal	12 Mg Magnesium Alkaline Earth Metal											13 Al Aluminum Post-Transition Metal	14 Si Silicon Metalloid	15 P Phosphorus Nonmetal	16 S Sulfur Nonmetal	17 Cl Chlorine Halogen	18 Ar Argon Noble Gas
19 K Potassium Alkali Metal	20 Ca Calcium Alkaline Earth Metal	21 Sc Scandium Transition Metal	22 Ti Titanium Transition Metal	23 V Vanadium Transition Metal	24 Cr Chromium Transition Metal	25 Mn Manganese Transition Metal	26 Fe Iron Transition Metal	27 Co Cobalt Transition Metal	28 Ni Nickel Transition Metal	29 Cu Copper Transition Metal	30 Zn Zinc Transition Metal	31 Ga Gallium Post-Transition Metal	32 Ge Germanium Metalloid	33 As Arsenic Metalloid	34 Se Selenium Nonmetal	35 Br Bromine Halogen	36 Kr Krypton Noble Gas
37 Rb Rubidium Alkali Metal	38 Sr Strontium Alkaline Earth Metal	39 Y Yttrium Transition Metal	40 Zr Zirconium Transition Metal	41 Nb Niobium Transition Metal	42 Mo Molybdenum Transition Metal	43 Tc Technetium Transition Metal	44 Ru Ruthenium Transition Metal	45 Rh Rhodium Transition Metal	46 Pd Palladium Transition Metal	47 Ag Silver Transition Metal	48 Cd Cadmium Transition Metal	49 In Indium Post-Transition Metal	50 Sn Tin Post-Transition Metal	51 Sb Antimony Metalloid	52 Te Tellurium Metalloid	53 I Iodine Halogen	54 Xe Xenon Noble Gas
55 Cs Cesium Alkali Metal	56 Ba Barium Alkaline Earth Metal	*	72 Hf Hafnium Transition Metal	73 Ta Tantalum Transition Metal	74 W Tungsten Transition Metal	75 Re Rhenium Transition Metal	76 Os Osmium Transition Metal	77 Ir Iridium Transition Metal	78 Pt Platinum Transition Metal	79 Au Gold Transition Metal	80 Hg Mercury Transition Metal	81 Tl Thallium Post-Transition Metal	82 Pb Lead Post-Transition Metal	83 Bi Bismuth Post-Transition Metal	84 Po Polonium Metalloid	85 At Astatine Halogen	86 Rn Radon Noble Gas
87 Fr Francium Alkali Metal	88 Ra Radium Alkaline Earth Metal	**	104 Rf Rutherfordium Transition Metal	105 Db Dubnium Transition Metal	106 Sg Seaborgium Transition Metal	107 Bh Bohrium Transition Metal	108 Hs Hassium Transition Metal	109 Mt Meitnerium Transition Metal	110 Ds Darmstadtium Transition Metal	111 Rg Roentgenium Transition Metal	112 Cn Copernicium Transition Metal	113 Nh Nihonium Post-Transition Metal	114 Fl Flerovium Post-Transition Metal	115 Mc Moscovium Post-Transition Metal	116 Lv Livermorium Post-Transition Metal	117 Ts Tennessine Halogen	118 Og Oganesson Noble Gas
		*	57 La Lanthanum Lanthanide	58 Ce Cerium Lanthanide	59 Pr Praseodymium Lanthanide	60 Nd Neodymium Lanthanide	61 Pm Promethium Lanthanide	62 Sm Samarium Lanthanide	63 Eu Europium Lanthanide	64 Gd Gadolinium Lanthanide	65 Tb Terbium Lanthanide	66 Dy Dysprosium Lanthanide	67 Ho Holmium Lanthanide	68 Er Erbium Lanthanide	69 Tm Thulium Lanthanide	70 Yb Ytterbium Lanthanide	71 Lu Lutetium Lanthanide
		**	89 Ac Actinium Actinide	90 Th Thorium Actinide	91 Pa Protactinium Actinide	92 U Uranium Actinide	93 Np Neptunium Actinide	94 Pu Plutonium Actinide	95 Am Americium Actinide	96 Cm Curium Actinide	97 Bk Berkelium Actinide	98 Cf Californium Actinide	99 Es Einsteinium Actinide	100 Fm Fermium Actinide	101 Md Mendelevium Actinide	102 No Nobelium Actinide	103 Lr Lawrencium Actinide

Figure 2.3: Periodic Table.

Source: https://pubchem.ncbi.nlm.nih.gov/periodic-table/png/Periodic_Table_of_Elements_w_Chemical_Group_Block_PubChem.png

2.3.1. Long Form of the Periodic Table

The elements were organized in the long form of the periodic table because that arrangement was apt for the electronic configuration of the elements as well as the physical and chemical properties of the elements.

Some significant aspects of the modern atomic structure applied to the classification of elements are given below:

Chemical reaction is a process that leads to the chemical transformation of one set of chemical substances to another.

- During a **chemical reaction** an atom either loses or gains electrons from the outermost shell.
- The sharing of one or more electrons by an atom with other one atom or more than one atom is significantly through the outer most orbit or valence shell. The electrons present in the outermost shell (called valence electrons) or the valence shell are used in identifying the properties of the elements.

Thus, it can be concluded that the elements having same outer electronic configurations must have same chemical and physical properties. Thus, they should be placed together for an easy as well as systematic study.

Taking into consideration all the things and reasons discussed before, the properties of elements re-occur at regular intervals or periodically, when the known elements are arranged in the ascending order of their atomic number in the periodic table.

2.4. STRUCTURAL FEATURES OF LONG FORM OF THE PERIODIC TABLE

Modern periodic table consists of 18 vertical columns called GROUPS. They are numbered from 1 to 18. Every group has a unique configuration. The periodic table also consists of seven horizontal rows called PERIODS. They are numbered from 1 to 7.

In the present day, 114 elements are known. There are 90 elements out of these 114 elements which occur naturally. The remaining elements either manufactured artificially or made using nuclear transformations. Any way they are **Manmade Elements**, but we will notice that this term is specifically applicable to transuranic elements (elements listed after uranium) only.

Periodic table is a tabular display of the chemical elements, which are arranged by atomic number, electron configuration, and recurring chemical properties.

The first period of the **periodic table** comprises of two elements thus, referred as very short period. Second and third period comprises of eight elements each thus, referred as short period. Fourth and fifth period comprises of 18 elements each thus, referred as long periods. Sixth period is made up of 32 elements thus, referred as long period. Seventh period is still incomplete and more elements are expected to be discovered and added as the scientific research advances.

Also, some name is assigned to few groups as per the similarity in their properties. These names are given below:

- Group 1 elements (except hydrogen) are referred as **Alkali Metals**
- Group 2 elements are referred as **Alkaline Earth Metals**

- Group 3 to 12 elements are referred as **Transition Metals**
- Group 16 elements are referred as **Chalcogens**
- Group 17 elements are referred as **Halogens**
- Group 18 elements are referred as **Noble Gases**.

Furthermore, the elements from atomic numbers 58 to 71 are called *Lanthanoids* – or Inner Transition elements (First series). Elements from atomic numbers 90 to 103 are called *Actinoids* – or Inner Transition elements (Second series). Main group elements are those elements which are neither transition nor inner transition. All elements except transition and inner transition elements are also collectively called **Main Group Elements.**

2.5. POSITION OF METALS, NON-METALS, AND METALLOIDS

For the purpose of locating the position of metals, non-metals, and metalloids in the modern periodic table, you can draw a diagonal line joining the element with atomic number 5 (Boron) with the element with atomic number 52 (Tellurium) passing through arsenic and silicon. Now the aforesaid basis following observations can be made:

- The elements above the diagonal line and to the extreme right are categorized as non-metals except selenium which shows little metallic nature. The non-metallic character of an element increases as the element is farther from the diagonal line and up.

- The elements below the diagonal line and to the extreme left are metals exception is hydrogen as it is a non-metal. The metallic character of an element increases as the element is farther from the diagonal line and down. All lanthanoids and actinoids are also metals.

The elements which lie along the diagonal line are called metalloids. Metalloids are elements which possess the properties of both metals as well as non-metals. Some elements like selenium, **antimony** and germanium, also possess the properties of metalloids.

Antimony is a chemical element with the symbol Sb and atomic number 51.

2.6. CATEGORIZATION OF ELEMENTS INTO S, P, D, AND F BLOCK

There is another way of grouping the elements in the periodic table, which is more related to their electronic configuration. For this type of categorization, it is important to know the location of **differentiating electron** (the last electron). For instance, if the electron has gone to '*s*-subshell,' the elements will fall in '*s*-block' and if the last electron goes to '*p*-subshell,' then the element will belong to *p*-block.

Similarly, if the last electron goes to the '*d*-subshell,' of an atom, then the elements consisting of all such atoms will fall in d-block. Some minor exceptions are seen in Mn and Zn.

The categorization of elements discussed above is relatable to the type of elements discussed earlier. The relation can be explained as:

- *s*-block elements: All alkali metals and, alkaline earth metals (group 1 and group 2).
- *p*-block elements: All elements of group number 13 to group number 18.
- *d*-block elements: All elements from group number 3 to group number 12 except Lanthanoids and Actinoides.
- *f*-block elements: Lanthanoids (atomic number 58 to 71) and Actinoids (atomic number 90 to 103).

2.6.1. Nomenclature of Elements with Atomic Numbers Greater Than 100

The naming of the new elements was initially left entirely to its discoverer. The suggested names to these elements was ratified by IUPAC (International Union of Pure and Applied Chemistry) later. But some disputes developed over the actual discoverer of some of the elements with atomic number more than 104.

Therefore, in 1994, IUPAC appointed a Commission on Nomenclature of Inorganic Chemistry (CNIC). Finally, after consulting the Commission and chemists from all around the world, in 1997, IUPAC recommended to follow a nomenclature for naming the newly discovered elements with atomic number more than 103 until their names are fully recognized.

The names are derived directly from the atomic number of the element using the following numerical roots for 0 and numbers 1–9.

0 = nil

1 = un

2 = bi

3 = tri

4 = quad

5 = pent

6 = hex

7 = sept

8 = oct

9 = enn

Roots are put together in the order of the digits which make up the atomic number and ‘ium’ is added at the end. Names, thus derives, and the IUPAC approved names of some elements with atomic numbers greater than 103.

- Nomenclature of elements with atomic numbers greater than 103

Atomic number	**Name**	**Symbol**	**IUPAC approved name**	**IUPAC symbol**
104	Unnilquadium	Unq	Rutherfordium	Rf
105	Unnilpentium	Unp	Dubnium	Db
106	Unnilhexium	Unh	Seaborgium	Sg
107	Unnilseptium	Uns	Bohrium	Bh
108	Unniloctium	Uno	Hassium	Hs
109	Unnilennium	Une	Meitnerium	Mt
110	Ununnillium	Uun	–	–
111	Unununnium	Uuu	–	–
112	Ununbium	Uub	–	–
113	Ununtrium	Uul	–	–
114	Ununquadium	Uuq	–	–
115	Ununpentium	Uup	–	–

2.7. PERIODICITY IN ATOMIC PROPERTIES

Periodicity refers to some characteristic properties which fall in the periodic table after regular intervals or indicates the repetition of properties after regular intervals. However, these characteristic properties though remain same but they differ in magnitude. Therefore, starting from a certain point in a periodic table, there is a surety that the movement in a certain direction will present a gradual decrease or increase in a property being talked about.

2.7.1. Atomic Size

Diatomic molecules are molecules composed of only two atoms, of the same or different chemical elements.

Bond length refers to the distance between the center of one nucleus to the center of another nucleus in a homonuclear **diatomic molecules**. Half of the distance of this bond length is referred to as atomic radius. The first member possesses largest size of every period.

Therefore, it can be concluded that the atom of group 1 are the largest in their respective horizontal rows. Similarly, the atoms of group 2 elements are large but smaller as compared to the corresponding atoms of group 1 element.

This happens because of the presence of extra charge on the nucleus which pulls the electron towards itself, as result the size of the atom decreases. Thus, we can say, on moving left to right in a period, the atomic size of an atom of an element decreases. However, some exceptions might be observed and they have other reasons for their explanations.

When we move top to bottom in a group or any particular column, the atomic size of an atom of an element increases. This is because on moving down the group, the atomic number increases and thus an extra shell gets added when we move from one element to another down the group.

Hence, the size increases.

For example: It can be observed in the following table that on moving down from Lithium to sodium and from Sodium to Potassium there is an increase in shell number. Therefore, among the three, Lithium bears smallest atomic size and Potassium has maximum atomic size.

Table 2.1: Electronic Configuration of Li, Na, and K

Element	Electronic Configuration
Lithium (Li)	2, 1
Sodium (Na)	2, 8, 1
Potassium (K)	2, 8, 8, 1

2.7.2. Ionic Size

An ion is formed as result of either gain or loss of electrons. When an atom readily loses the electron from its outermost or valence shell, a cation is formed. For example, Sodium (Na) readily loses an electron to from sodium ion (Na^+). When an atom becomes charged, it is called ion and when it is positively charged, it is called cation. The size of a cation is smaller in comparison the size of an atom.

This happens because once the electron is removed from the atom in order to form a cation, the positive charge of the nucleus acts on comparatively lesser number of electrons as compared to the neutral atom and thus resulting in greater pull by nucleus, hence decreasing the size of the cation.

When an electron readily gains or accepts electron in the outermost or valence shell, it forms an anion. An anion is positively charged. For example, Chlorine (Cl) gains an electron in order to form chloride ion (Cl^-). The size of an anion is greater the size of a neutral atom. This is because as the electrons in the outermost shell increases, the negative charge also increases which outweighs the positive charge. Thus, the hold on the shells by nucleus decreases, resulting in the increased size of an anion.

The size of the cation is always less as compared to the size of its atom, whereas the size of an anion is always greater as compared to the size of its atom.

A cation is always smaller than its atom and an anion is always bigger than it's atom, e.g., Na^+ is smaller than Na, Cl^- is bigger than Cl.

Ionic radii is the measure of an atom's ion in a crystal lattice.

There is an increase in **ionic radii** in the main groups on moving top to bottom in a group. e.g., Li^+ = 0.76

Å, Na^+ = 1.02 Å, K^+ = 1.38 Å, etc. It is because an extra shell or orbit is added at each step.

As we move left to right in a period, the ionic radii of the positive ion tend to decrease. e.g., Na^+ = 1.02 Å, Mg^{2+} = 0.72 Å, $Al3^+$ = 0.535Å, etc. It is because of the increase in the number of charges on the nucleus and also because of the increase in the charge on the ion.

While moving left to right in a period, the ionic radii of the negative ions also tend to decrease. e.g., O^{2-} = 1.40 Å, F^- = 1.33 Å, etc. This is partly because of the number of charges on the nucleus increases and also because the charge on the ion decreases.

Bound electron is an electron that is held in an orbit around a nucleus.

2.7.3. Ionization Enthalpy

The amount of energy needed to knock out the loosely **bound electron** from the isolated atom in its gaseous state when element is present in one mole. The unit used to express ionization enthalpy is kJ/mol (kiloJoules per mole). On moving left to right in a period, roughly there is a regular increase in the value of the ionization enthalpy of an element.

Similarly, while moving top to bottom in a group, there is a regular decrease in the magnitude or the value of the ionization enthalpy. The first member of any group possesses highest ionization enthalpy within that particular group. The last member of any group possesses least ionization enthalpy within the same group.

The factor which effect the magnitude or the value of the ionization enthalpy are given below:

- The size of the atom: Ionization enthalpy decrease with the increase in the atomic size. This is because, if the size of atom is small then the electron will be bound tightly whereas as the size increases, the distance from the nucleus also increases, thus weakening the pull exerted by the nucleus. This allows easy removal of electron thereby decreasing the ionization enthalpy.
- The magnitude of the nuclear charge on the atom: Nuclear charge is defined as the ratio of the number of charges present on the nucleus to the number of electrons. With the removal of an electron, an increase in the effective nuclear charge is observed. The other remaining electrons after the removal of one experience a stronger pull by the nucleus, as they are now comparatively nearer to the nucleus.

Therefore, the removal of the second electron from an atom is very difficult or requires a large amount of energy. For example, Mg^+ is smaller than the Mg atom the remaining electrons in Mg^+ are more tightly held. The second ionization enthalpy is, therefore, more than the first ionization enthalpy.

- The type of orbital involved (*s*, *p*, *d*, or *f*): Due to the difference in the shape of the orbitals (*s*, *p*, *d*, and *f*), the ionization enthalpy depends on the type of electron removed. For instance, an electron present in *s* orbital requires larger ionization enthalpy because the electrons present in *s* orbitals are strongly bound by the nucleus in comparison to the electrons of *p* orbital. This happens because the electrons present in *s* orbital are close to the nucleus as compared to the electrons in *p* orbital. Similarly, the electrons of *p* orbitals are more strongly bound to the nucleus as compared to the electrons present in *d* orbital and further the electron of *d* orbitals are more strongly held as compared to the electrons of *f* orbitals. If all other factors are equal, the ionization enthalpies are in the order $s > p > d > f$.

All the above-discussed factors contribute largely to account for the extent of force of attraction present between the nucleus and the electrons around it. As a result of these factors, one can thus determine the magnitude of the ionization enthalpy of an element.

- Least ionization enthalpy is observed in the group 1 metals 1 (Li, Na, K, Rb, etc.) in their respective periods.
- Maximum ionization enthalpy is observed in group 18 noble or inert gases (He, Ne, Ar, Kr, Xe and Rn) in their respective periods. Since they have fully filled stable shells, it is difficult to remove an electron. Hence, the amount of energy required is quite high.
- The values of ionization energies do not increase at a regular pace. For, e.g., the first ionization enthalpy of B (Boron) is less as compared to that of Be (Beryllium); the ionization enthalpy of Al (Aluminum) is less as compared to that of Mg (Magnesium); the first ionization enthalpy of O (Oxygen) is less as compared to that of N (Nitrogen). The explanation for this as follows:

The first **ionization** enthalpies of Be and Mg are higher in comparison to their preceding elements because the electrons are to be removed from the fully filled s-orbitals. Since fully filled orbitals are more stable, hence more energy is required.

Ionization is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons, often in conjunction with other chemical changes.

The first ionization enthalpy of Nitrogen is greater as compared to that of Oxygen, because it is difficult to remove an electron from half-filled p-orbitals, which is the case of nitrogen. Ionization enthalpy is an absolute value and can be determined experimentally.

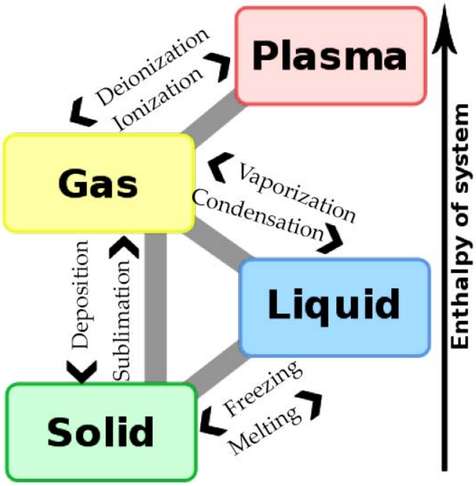


Figure 2.4: Ionization enthalpy.

Source: https://visionaryleadership.com/phase-change/

2.7.4. Electron Gain Enthalpy

In general, every atom has a tendency to either loose or gain electrons in order to attain a stable or noble gas configuration. The atoms having valence electrons as five, six or seven have tendency to accept or gain electrons in order to achieve a noble gas configuration. For example, Halogens (Group 17) have seven valence electrons.

Thus, it is easier to accept or gain one electron in order to achieve noble gas configuration. The change in energy during this process is termed as electron gain enthalpy. Hence, electron gain enthalpy is defined as the amount of energy absorbed or released for one mole of neutral atoms in a gaseous state when electron is accepted by each atom. The negative value marks release of energy and hence tendency to greater stabilization. As we move left to right in a period, the electron gain enthalpy becomes more negative. This is because it is more convenient to accept or gain an electron for a smaller atom than to remove electron as the accepted electron would be closer to the nucleus which is positively charged.

A maximum amount of energy is evolved when electron is accepted by a halogen family. On the contrary, the metals (elements which lose electrons readily) do not accept electrons and indicates a high positive electron gain enthalpy. Hence electron gain **enthalpy** can be negative or positive. On moving down the group the electropositive character of the atoms increases as the electron gain enthalpy becomes less negative. This happens because while moving down the group there is an increase in the atomic size and the electron which is added goes to the higher shells.

Enthalpy is the sum of the internal energy and the product of the pressure and volume of a thermodynamic system.

The electron gain enthalpy value of chlorine is more towards negative side than that of fluorine. This is because of the small size of the fluorine atom. Due to the small size the approaching electrons experiences repulsion from other electrons.

2.8. ELECTRONEGATIVITY

It indicates the extent of attraction by which the electrons of the bond pair are attracted by an atom linked by this bond.

The magnitude of electronegativity is allotted randomly to one atom such as hydrogen. Then the magnitude of electronegativity is allotted to all other atoms with respect to hydrogen. One such scale is the **Pauling Scale of electronegativity**.

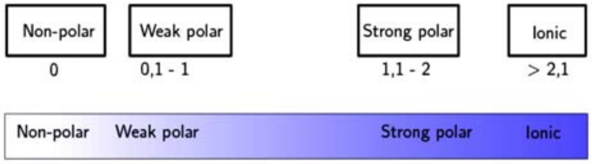


Figure 2.5: Electronegativity.

Source: https://www.siyavula.com/read/science/grade-11/atomic-combinations/03-atomic-combinations-03

Measurement of the capability of an atom to attract the electron pair in a covalent bond to itself is termed as electronegativity.

In a homonuclear diatomic molecule like hydrogen (H_2) or fluorine (F_2), the electron pair of the covalent bond in each molecule undergo equal attraction by each atom. Thus, out of the two, not even a single atom is capable to shift the bond pair of electrons to itself.

However, in case of a heteronuclear diatomic molecule, the bond pair electrons get shifted towards the atom that is more electronegative than the other. For instance, in HCl or HF the bond pair of electrons is not shared equally but the more electronegative atom Cl or F has potential of shifting the bond pair towards itself, which results in the polarization of the molecule. High ionic character of the bond between the two atoms is marked by a large difference in their electronegativities. For example: Cs^+ F^-. Whereas, the percentage ionic character zero is denoted as a result of no difference in the electronegativities. Hence, the molecule is purely covalent, e.g., H_2, Cl_2, N_2, etc.

Excluding the noble gases, the elements located on the extreme right upper corner on the periodic table are most electronegative ones. On moving left to right in a periodic table the **electronegativity** increases while on going down in a group, the electronegativity of an element decreases. Therefore, the most electronegative element is fluorine and the least electronegative element is cesium (not considered Francium being radioactive).

Electronegativity is a measure of the attraction of an atom for bonding electrons in molecules compared to that of other atoms.

REVIEW QUESTIONS

1. What are the atomic properties of elements?
2. Describe the classification of elements based on their size.
3. Explain Dobereiner's Law of Triads.
4. Discuss Newlands' Law of octaves.
5. What do you understand by periodicity?
6. Write advantages and disadvantages of Mendeleev's periodic table.
7. Explain the evolution of modern periodic table.
8. What are the structural features of long form of the periodic table?
9. Define ionization enthalpy.
10. What do you mean by the term "electronegativity"?

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CHAPTER

3

SOLUTIONS AND PROPERTIES OF SOLUTIONS

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- The definition of chemical solution and their properties
- Solubility and equilibrium in solution
- The process of recrystallization
- Ideal and non-ideal solutions
- The Raoult’s law

KEYWORDS

- Colligative Properties
- Colloids
- Crystallization
- Ideal Solutions
- Ionic Compounds
- Non-Ideal Solutions
- Osmotic Pressure
- Raoult’s Law
- Re-Crystallization
- Solution
- Solvents

3.1. AN INTRODUCTION TO SOLUTION

Solutions can be defined as a homogeneous mixture that consist of two components, namely Solvent and Solute(s). The solutions can be categorized further on the basis of different concentration of Solvent and Solute. For example,

- An aqueous solution has water as a solvent.
- A concentrated solution consists of more amount of dissolved solute as compared to solvent.
- A dilute solution is the one with very low amount of dissolved solute(s).
- A saturated solution is the one in which no more solute can be dissolved at a specific temperature without altering the natural conditions.
- A supersaturated solution is the one that has more amount of dissolved **solute**(s) as compared to what it normally has to do to give a saturated solution at a specific temperature.

Figure 3.1: Chemical solutions.

Source: https://www.interelectronix.com/en/touch-screen-chemically-resistant.html

3.1.1. Types of Solutions

The table mentioned below describes the various types of solutions depending upon the state of solvent and solute that is, gases, liquid and solids.

Table 3.1: Types of Solutions Depending Upon the State of Solvent and Solute

State of Solvent	State of Solute	State of Solution	Examples
Gas	Gas	Gas	Air, Natural gas
Liquid	Liquid	Liquid	Alcoholic beverages, Antifreeze solution
Liquid	solid	liquid	Seawater, Sugar solution
Liquid	gas	liquid	Carbonated water (soda), Ammonia solution;
Solid	solid	solid	Metal alloys: Brass, Bronze
Solid	gas	solid	Hydrogen in platinum

3.2. SOLUBILITY AND EQUILIBRIUM IN SOLUTION

The definition of **solubility** can be stated as: At a specific temperature, the solubility of any substance is the quantity of Solute (by weight), that is dissolved in a particular amount of solvent in order to give a Saturated solution.

A **saturated solution** can be defined as the "one that contains the maximum quantity of dissolved solute that is normally possible at a given temperature, where a state of **dynamic equilibrium** exists between dissolution and crystallization."

From this definition, it can be derived that solubility is temperature dependent. For example, taking in account the solubility of KNO_3, which is 30 grams per 100 grams at a temperature of 20°C while it is 63 grams per 100 grams water at a temperature of 40°C.

Further, it has also been noted that at higher temperatures, when a solution is at the state of almost saturation is brought down to a lower temperature where solubility is lower, the solute

Solute is a substance that can be dissolved by a solvent to create a solution.

in excess would get precipitated to provide a saturated solution at the lower temperature.

Dynamic equilibrium is an example of a system in a steady state. This means the variables in the equation are unchanging over time (since the rates of reaction are equal).

However, if the cooling process of this solution happens very rapidly and solute did not get enough time to seed, precipitation will not happen and the resulting solution will consist of more dissolved amount of solute as compared to what it contains in a normal saturated solution. The solution hence obtained is called super saturated solution.

To define **Supersaturated solution**, it can be stated that "one that contains more dissolved solute than it normally possible under normal condition. The solution is unstable and crystallization will occur readily by seeding (introducing particles that provide nuclei for precipitation)."

3.3. RE-CRYSTALLIZATION OR FRACTIONAL CRYSTALLIZATION

Supersaturated solution is a solution that contains more than the maximum amount of solute that is capable of being dissolved at a given temperature.

As the solubility is directly proportionate to the temperature for most of the compounds and increase with rise in temperature, fractional crystallization can be performed in order to purify some of the compounds. For a good recovery, the only condition is that to perform the process of re crystallization, the substance must have very high solubility at higher temperature and very low solubility at lower temperature.

For example, KNO_3 (potassium nitrate) has a solubility of about 63 g per 100 g water (H_2O) at 40°C, and 15 g per 100 g H_2O at 0°C. If a saturated solution of KNO_3 at 40°C is cooled to 0°C, 45 g of solid KNO_3 will crystallize out.

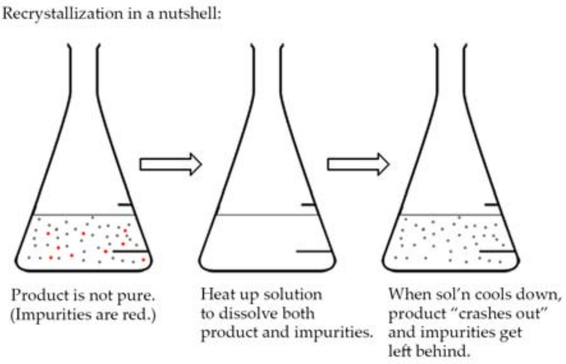


Figure 3.2: Recrystallization.

Source: http://umich.edu/~chemh215/W14HT-ML/SSG1/SSG1.2/Recrystallization.html

3.3.1. Composition of Solutions

Concentration of a solution tells about the amount of solute present in the solution. There are several units of concentration as mentioned below:

Units of Concentration:

1. Volume Percent% (v/v) = $\frac{\text{Volume of Solute}}{\text{Volume of Solution}} \times 100\%$
2. Mass Percent, % (w/w) = $\frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100\%$
3. Molality (m) = $\frac{\text{No. of moles of solute}}{\text{Kilograms of solvent}}$
4. Molarity (M) = $\frac{\text{No. of moles of solute}}{\text{Liters of solution}}$
5. Normality (N) = $\frac{\text{No. of equivalent of solute}}{\text{Liters of solution}}$
6. Mole fraction, X_i = $\frac{\text{Mole of a component}}{\text{Total moles of components in solution}}$

3.3.2. The Energy of Solution Formation

The formation of a solution by mixing two or more compounds is a process that in cases, requires energy or releases energy. This process is explained below.

The steps involved in the formation of a solution are:

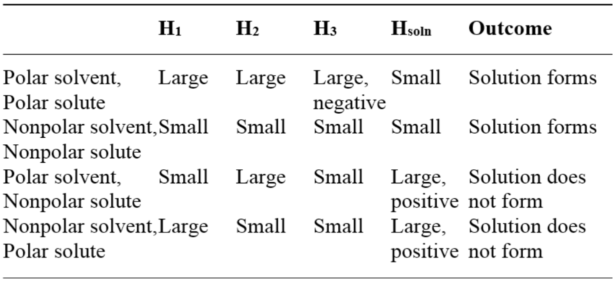
1. Pure solute → separated solute particles; $H_1 > 0$; (endothermic process)
2. Pure solvent → separated solvent molecules; $H_2 > 0$; (endothermic process)
3. separated solvent and solute molecules → solution; $H_3 < 0$; (exothermic process)

There is some amount of energy that is required to break the **intermolecular forces** in the solute and solvent, so as to separate the ions or molecules from each other. In cases when molecules are mixed to get a solution, intermolecular interaction increases considerably and some energy is disposed of.

Intermolecular forces are the forces which mediate interaction between molecules, including forces of attraction or repulsion which act between molecules and other types of neighboring particles, e.g., atoms or ions.

The Energy Terms for Different Types of Solvents and Solutes:

Table 3.2: Different energy terms of different solvents and solutes



	H_1	H_2	H_3	H_{soln}	Outcome
Polar solvent, Polar solute	Large	Large	Large, negative	Small	Solution forms
Nonpolar solvent, Nonpolar solute	Small	Small	Small	Small	Solution forms
Polar solvent, Nonpolar solute	Small	Large	Small	Large, positive	Solution does not form
Nonpolar solvent, Polar solute	Large	Small	Small	Large, positive	Solution does not form

3.3.3. Different Interaction Types of Solvent-Solute

- Ion-induced dipole;
- Permanent dipole-induced dipole attractions;
- Ion-dipole attractions;
- Permanent dipole-dipole attractions;
- Hydrogen bonding; and
- London dispersion forces.

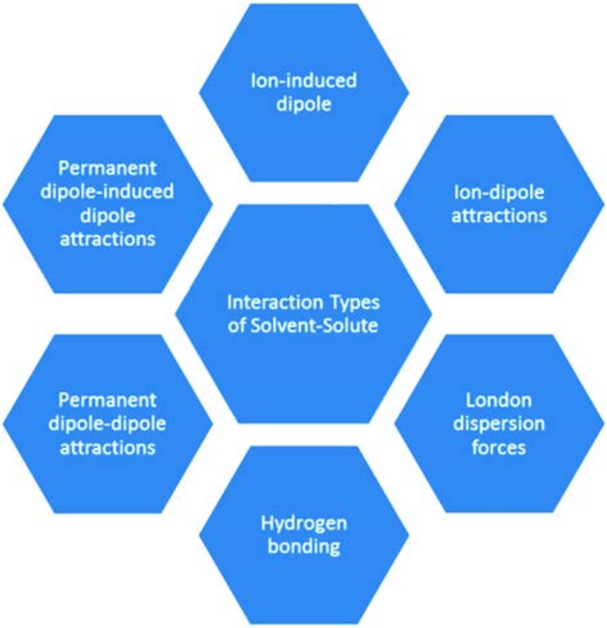


Figure 3.3: Different types of solvent-solute interactions.

3.4. IONIC COMPOUNDS AND FORMATION OF SOLUTIONS

A lot of ionic compounds easily dissolve in water and not in nonpolar or organic solvents.

Water molecules are polar in nature and interact very effectively with ionic counterparts, i.e., anions and cations with the help of ion-dipole interactions.

Solvation is an interaction of a solute with the solvent, which leads to stabilization of the solute species in the solution.

These types of interactions give output in form of negative enthalpies, which is known as hydration or **solvation** energy. The complete process of solution formation can either be endothermic or exothermic in nature, depending upon the fact that which enthalpy is larger. Here mentioned is the process of dissolution of NaCl solution:

1. Dissociation of NaCl into gaseous ions:

$NaCl_{(s)} \rightarrow Na^{+}_{(g)} + Cl^{-}_{(g)}$; $H_1 = 786$ kJ/mol

2. Hydration of Na^+ ions:

$Na^{+}_{(g)} + nH_2O \rightarrow Na^{+}_{(aq)}$; $H_2 = -844$ kJ/mol

3. Hydration of Cl^- ions:

$Cl^{-}_{(g)} + nH_2O \rightarrow Cl^{-}_{(aq)}$; $H_3 = 61$ kJ/mol

Net: $NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$; $DH_{soln} = DH_1 + DH_2 + DH_3 = 3$ kJ/mol

The process of formation of NaCl solution is somewhat endothermic in nature. But the question arises that how can an **endothermic process** be so spontaneous? The answer is that the major driving factor/ force in formation of solution is in high disorder, or is in the state of higher entropy in the solution as compared to the solid NaCl (original).

It is also known that a solution formed with $H_{soln} = 0$ is termed as an Ideal Solution. Any other solution diverting from this or having a positive or negative H_{soln} are nonideal solutions. The main point that must be taken into consideration is that intermolecular interactions between the solvent and solute particles plays an important role in the fact that whether a solute will dissolve or not in a given solvent, or whether final received solution is non-ideal or ideal solution.

Endothermic process is any process which requires or absorbs energy from its surroundings, usually in the form of heat.

3.5. MAJOR FACTORS INFLUENCING SOLUBILITY

3.5.1. Structural Effects

A correlation can be observed in between the solubility and molecular structure. A solution will be obtained in case, when both solvent and solute possess alike polarity, molecular structure and kind of interaction – "like dissolves like." For example, nonpolar substances like oil and grease are soluble in non-polar solvent like gasoline (C_8H_{18}) and hexane (C_6H_{14}). Polar and ionic compounds like mineral acids, sugar and salts are easily soluble in polar solvents like methanol and water.

3.5.1.1. Temperature Effects

In general cases, temperature and solubility of solids is directly proportional to each other and solubility increases with increase in the temperature. This states that dissolving of solid substances is an endothermic process ($H_{soln} > 0$).

As per the Le Chatelier's principle "an endothermic process favors high temperature." In some cases, the solubility of few ionic compound that consist of SeO_4^{2-}, SO_3^{2-}, AsO_4^{3-}, PO_4^{3-} and SO_4^{2-} is found to reduce as the rise in temperature is noted. Negative enthalpy of solution is noted in these compounds ($H_{soln} < 0$).

In cases, where solute is in gaseous form and solvent is in liquid form, the solubility is inversely proportional to the temperature and hence the solubility decreases with the increase in temperature. This shows that dissolving gases in liquid solvent is an exothermic process and heat is released when a gas is dissolved. And gases are easily soluble at lower temperatures as compared to the high temperature.

This dissolution of gases and temperature effect in water has seen a widespread application around the globe and this solubility of gases has a negative impact on environment and this result in extensive and unwanted use of water from natural sources like rivers and lakes in industrial cooling system.

The major concern is that used water from industries is then again released in the rivers and lakes, which is significantly warmers as compared to the natural ambient temperature and plays an important role in causing **thermal pollution**. This increase in ambient temperature of river or lake water decreases the amount of dissolved oxygen, which is a major concern for the survival of aquatic lives.

Thermal pollution is the degradation of water quality by any process that changes ambient water temperature.

3.5.2. Effect of Pressure

Pressure does not affect the solubility of liquids and solids substantially, but the solubility of gases increases with increase in the pressure. As per the Henry’s Law, “the solubility of gases is directly proportional to the partial pressure of the gas above the solution:”

C = kP

where, C = concentration of gas in solution, P = gas pressure above the solution, and k = Henry's constant characteristic of the gas and solvent. The standard unit to express the solubility of gases is mL of gas at STP per Liter of Solvent.

Henry's Law is followed precisely mostly for the solutions that are dilute solutions of gases that does not react or dissociate with the solvent. For example, Henry's law is followed by nitrogen and oxygen gases that are dissolved in solvent like water, but not by ammonia or carbon dioxide, as these gases react with water.

3.6. IDEAL AND NON-IDEAL SOLUTIONS

Taking in account a binary solution that consist of two components A and B, the type of interaction between these two is:

A ←→ A, A ←→ B, and B ←→ B

Case 1: Interactions: **A ←→ B** = **A ←→ A** = **B ←→ B**; V = 0 and H = 0

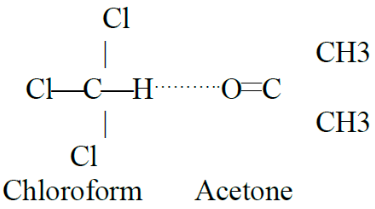
In the solutions that consist of hexane (C_6H_{14})–heptane (C_7H_{16}), benzene (C_6H_6)–toluene (C_7H_8), ethanol (C_2H_5OH)–methanol (CH_3OH), etc., intermolecular interactions between the non-identical molecules and those between the identical molecules are interrelated and are of similar magnitude. These types of solutions follow Raoult's law and are categorized as IDEAL solutions, where $P_A = X_A P_{\text{Å}}$.

Case 2: Interactions: **A ←→ B** > **A ←→ A** ~ **B**

$\leftarrow\rightarrow$ **B**; $V < 0$ and $H < 0$

In the cases where intermolecular interactions between the non-identical molecules are greater as compared to the identical molecules, the negative deviation from ideal characteristics are shown by solutions. For example, in a mixture of chloroform ($CHCl_3$) and acetone (C_3H_6O), the dipole-dipole interactions between the acetone and chloroform molecules are greater than the acetone-acetone and chloroform-chloroform interactions, individually.

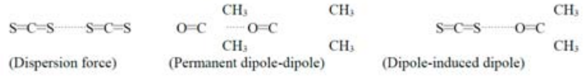
As per the Raoult's Law, the vapor pressure of the solution is marked lower than that calculated as compared to the ideal solution (that is, $P_A < X_A P_A$).



Case 3: Interactions: $\mathbf{A \leftrightarrow B < A \leftrightarrow A \sim B \leftrightarrow B}$; $V > 0$ and $H > 0$

Considering another kind of solutions, for example, mixture of acetone and carbon disulfide (CS_2), the interactions between the molecules of identical types are stronger as compared to the ones of non-identical types.

There is relatively stronger interaction between two polar acetone molecules as compared to one polar acetone molecule and interacting with non-polar **carbon disulfide** molecule and vice versa. A positive deviation is marked for these types of solutions from ideal characteristics. These solutions have higher vapor pressure as predicted using Raoult's Law for ideal solutions (that is, $P_A > X_A P_A$).



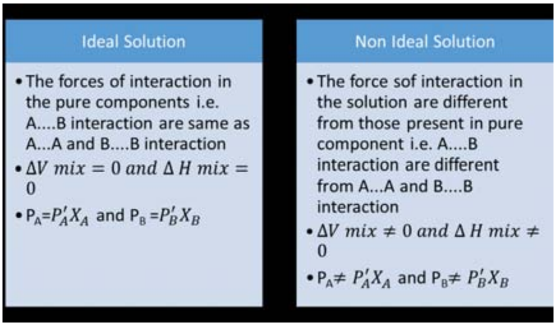
(Dispersion force) (Permanent dipole-dipole) (Dipole-induced dipole)

Case 4: In extreme cases, where the interactions are: **A ↔ B << A ↔ A ~ B ↔ B**,

These are the exceptional cases in which the solute and solvent do not mix up and instead two separate layers are formed in the solution, for example, mixing of water and oil.

Hence, there are enough strong interactions between the solute and solvent particles of the two different substances to form a solution. Solutions that consists of same kind of substances, where the interactions between the non-identical and identical components in a solution are relatively of same strength, tend to create ideal solutions that follow Raoult's Law.

Further, the solutions in which the strength of interaction between the non-identical and identical substances are distinct (either stronger interaction or weaker interaction), they diverge from ideal characteristics and not follow the Raoult's Law.



Ideal Solution	Non Ideal Solution
• The forces of interaction in the pure components i.e. A....B interaction are same as A...A and B....B interaction • $\Delta V\ mix = 0\ and\ \Delta\ H\ mix = 0$ • $P_A = P'_A X_A$ and $P_B = P'_B X_B$	• The force sof interaction in the solution are different from those present in pure component i.e. A....B interaction are different from A...A and B....B interaction • $\Delta V\ mix \neq 0\ and\ \Delta\ H\ mix \neq 0$ • $P_A \neq P'_A X_A$ and $P_B \neq P'_B X_B$

Figure 3.4: A Comparison between Ideal and Non-ideal Solution.

Carbon disulfide is a colorless volatile liquid with the formula CS_2. The compound is used frequently as a building block in organic chemistry as well as an industrial and chemical non-polar solvent.

3.7. RAOULT'S LAW: THE VAPOR PRESSURE OF SOLUTIONS

The constituents of a solution present in it highly impact the vapor pressure of solution. The Raoult's Law is followed by the vapor pressure of the solution, particularly in the cases of ideal solutions like of a liquid-liquid solution. As per Raoult' Law, "the vapor pressure due to each component is proportional to the mole fraction of that component in solution."

This means that for a solution that contains liquid A and B, the vapor pressure of component is:

$P_A = X_A.P^o_A$; $P_B = X_B.P^o_B$; $P_{total} = P_A + P_B$; where

where, P_A = vapor pressure of liquid A in solution; X_A = mole fraction of A in solution; P^o_A = vapor pressure of pure solvent; P_B = vapor pressure of liquid B in solution; X_B = mole fraction of B in solution; and P^o_B = vapor pressure of pure solvent.

Ideal solution is a solution with thermodynamic properties analogous to those of a mixture of ideal gases.

Ideal solutions are the ones that follow the Raoult's Law. For example, toluene and benzene forms an **ideal solution**. By using Raoult's equation, the vapor pressure of components and total vapor pressure of the solution can be evaluated from following equations:

$P_{bz} = X_{bz}.P^o_{bz}$; $P_{tol} = X_{tol}.P^o_{tol}$; $P_{total} = P_{bz} + P_{tol}$

Taking the example of benzene–toluene mixture, with the mole fractions in the liquid forms are $X_{bz} = X_{tol} = 0.500$ and the vapor pressure of pure toluene is 28.4 torr and vapor pressure of pure benzene is 95.1 torr, both at 25^0C, the vapor pressures of the solution of benzene–toluene at 25°C will be,

P_{bz} = (0.550 x 95.1 torr) = 47.6 torr; P_{tol} = (0.500 x 28.4 torr) = 14.2 torr;

P_{soln} = P_{bz} + P_{tol} = (47.6 + 14.2) torr = 61.8 torr.

The composition of vapor of benzene – toluene mixture at 25°C is:

$$Y_{bz} = (P_{bz}/P_{soln}) = (47.6/61.8) = 0.770;$$
$$Y_{tol} = (P_{tol}/P_{soln}) = (14.2/61.8) = 0.230;$$

After the condensation of this vapor, a liquid solution that composes 77.0% mole of benzene and 23.0% mole of toluene is obtained. On further distilling this distillate, a yield is be obtained that will compose more of benzene as it is more volatile of the two components.

In order to obtain pure benzene, the same process is repeated many more times, and the final distillate will be pure benzene. This is the core principle behind purifying the liquid mixtures by using the process of fractional distillation.

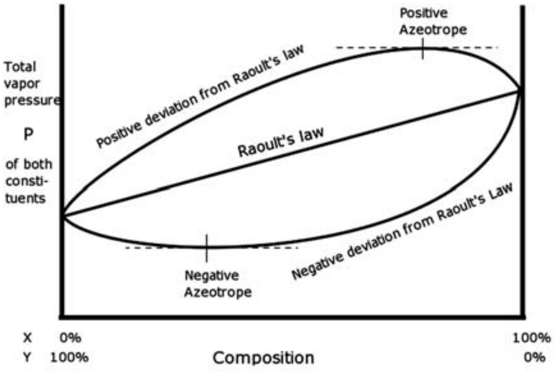


Figure 3.5: Positive and Negative Deviations from Raoult's Law.

Source: https://en.wikipedia.org/wiki/Raoult%27s_law

3.7.1. Applications and Practical Uses

Fractional distillation is the separation of a mixture into its component parts, or fractions.

Fractional Distillation can be used to purify the ideal liquid–liquid mixtures with the help of tall **fractional distillation** column. In the process of fractional distillation, compounds that are most volatile are obtained at the top of column while the compounds that are least volatile are obtained as residues and collected from the bottom of column. Fractional distillation is extensively used in petroleum industry to separate the components of crude oils and obtain the various petroleum products.

If the fractional distillation column is tall enough to separate the vapors, it can be used to get the pure components out of an ideal mixture. In case of non-ideal solutions, Azeotropic mixtures are obtained from fractional distillation.

Azeotropic mixture is the one that cannot be further separated with the help of fractional distillation as the amount of liquid mixture is the same as that of vapor mixture. For example, water–ethanol (C_2H_5OH) mixture produces an azeotrope mixture with the water composition of 4.4% and ethanol composition of 95.6%, by mass. The constant boiling point of this mixture is 78.2°C.

3.8. COLLIGATIVE PROPERTIES

Mixtures that contain non-volatile solutes have a different set of properties as compared to that of a pure solvent. The following physical changes in the solvent are observed during the presence of a non-volatile solute in a solution.

Solutions made using non-volatile solutes have significantly different physical properties as compared to pure solvent. There occur certain physical changes in a solvent due to the presence of non-volatile solutes in a solution. These physical changes are:

- The lowering of vapor pressure;
- The depression of freezing point;
- The elevation of boiling point; and
- The osmotic pressure exerted by the solution.

These properties of a solution are called colligative as these properties only depend on the concentration of solute present in the solution and not on kind of solute it is. The elevation of boiling point (T_b), the freezing point depression (T_f), and the osmotic pressure of solution are the effects that are directly related to the lowering of the vapor pressure (P) of solvent by non-volatile solutes.

To push the characteristics of a non-ideal solution towards the ideal behavior under condition like very dilute solution, the following standard relation can be put in action:

$$P = Po - P,$$

$$P = (1 - X_s)P^o = P^o - X_sP^o$$

$$P = P^o - P = X_sP^o \text{ (for non-electrolytes)}$$

$$= iX_sP^o \text{ (for electrolytes)}$$

In the above equations P is known as “lowering of vapor pressure” in any solution. This “lowering of vapor pressure” is in direct relation with the mole fraction of the dissolved solute. Vapor pressure of pure solvent is marked P^0, vapor pressure of solvent in the solution is marked P, mole fraction of the solute is X_s, and i represents the Van’t Hoff factor of the solute. The value for Van’t Hoff factor is equal to 1 for non-electrolytes and for strong electrolytes present in a very dilute solution, value of Van’t Hoff factor is approximately equals to the total number of ions present in a formula unit. For instance, the value of Van’t Hoff factor is roughly equals to 2 for a diluted NaCl solution.

3.8.1. The Elevation of Boiling Point and Freezing Point Depression

For a given solution, the freezing point of depression, T_f, is directly proportional to the molal concentration (m) of solution:

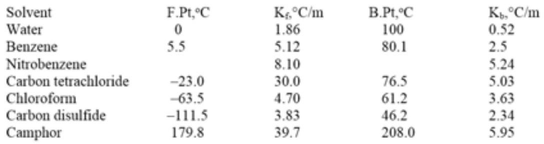
$T_f = Kfm$ (for non-electrolytes)
$T_f = iK_fm$ (for strong electrolytes)

Further, for a dilute solution, the elevation of boiling point, T_b, is proportional to the molal concentration of the solution:

$T_b = K_bm$, (for non-electrolytes)
$T_b = iK_bm$, (for strong electrolytes)

In the above equations, K_b and K_f are called boiling point elevation constant and freezing point lowering constant, respectively. In the expressions mentioned above, concentrations of solute are expressed in molal (m), which is mole of solute per kilogram of solvent. K_b and K_f values of some solvents are given below:

Table 3.3: Solvents and their melting and boiling points



Solvent	F.Pt,°C	K_f,°C/m	B.Pt,°C	K_b,°C/m
Water	0	1.86	100	0.52
Benzene	5.5	5.12	80.1	2.5
Nitrobenzene		8.10		5.24
Carbon tetrachloride	–23.0	30.0	76.5	5.03
Chloroform	–63.5	4.70	61.2	3.63
Carbon disulfide	–111.5	3.83	46.2	2.34
Camphor	179.8	39.7	208.0	5.95

3.8.1. Osmotic Pressure

If a solution that contains a nonvolatile solute and a pure solvent are separated by using a semi-permeable membrane, a net flow of a solvent molecule across the membrane of the solution is noticed. This quick net movement of solvent molecules via a semi permeable membrane from a dilute solution or a pure solvent into a more concentrated solution is called osmosis. **Osmotic pressure** (Π) of the solution is "the pressure required to stop the net spontaneous flow of solvent molecules across a semi-permeable membrane." Osmotic pressure of a dilute solution is given as,

Osmotic pressure is the minimum pressure which needs to be applied to a solution to prevent the inward flow of its pure solvent across a semipermeable membrane.

$\Pi = MRT = (n/V)RT$, (for non-electrolytes),

$\Pi = iMRT = i(n/V)RT$ (for strong electrolytes)

(M is molar concentration of the solution)

For an aqueous solution, if a pressure more than osmotic pressure is applied, water can be pushed out of the solution via semi-permeable membrane. This process is known as reverse osmosis. This method is extensively used in getting fresh water from seawater. The reverse osmosis process consumes a lot of energy.

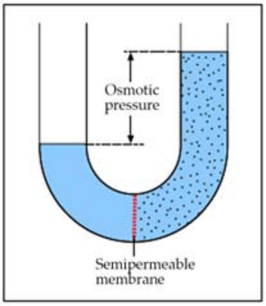


Figure 3.6: Osmotic pressure.

Source: https://www.memorangapp.com/flashcards/73522/Solution+Chemistry+II/

3.9. COLLOIDS

Colloids are the mixtures that lie between a heterogeneous mixture and a true solution. In a colloidal mixture, the particle size of solute is much larger as compared to the solvent molecules, but are too small to be seen with the help of a light microscope.

Colloids are very small particles in which a substance is divided into and the substance are dispersed through a second substance. The size of the particles of the second substance is much larger in comparison to the ones that are there in the solution, though they are so small that they can only be viewed in a microscope. The size of the colloidal particles tends to range from 10^{-9} m to 10^{-6} m. The mixture is known as a **colloidal solution** or a colloidal system and such systems may be formed from the combination of the three states namely, solid, liquid and gas. A colloidal system cannot be called a true solution as it does not settle and can be called a suspension.

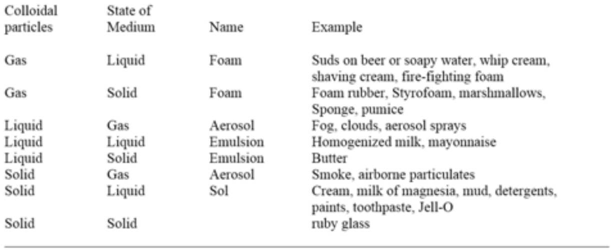
Colloidal solution is a solution *in which a material is evenly suspended in a liquid. In other words, a* colloid *is a microscopically small substance that is equally dispersed throughout another material.*

Colloidal particles are generally dispersed in a medium that is homogeneous like air or water. In case of colloids, to differentiate them from solutions, terms like dispersed substance and dispersed medium are used in place of solute and solvent.

In a lot of cases, many colloidal particles are seen to be composed of small particles that are bind together with the help of intermolecular forces. Some of the examples of this case are soaps and detergents, which are colloidal particles made of clusters of small particles. In water, detergents and soaps form clusters called micelles, which include inner hydrophobic regions. One other example of cluster of small particles is smoke. Below mentioned table describes the various colloids, their state and some common examples.

3.9.1. Types of Colloids

Table 3.4: Colloidal Particles and their state of medium



Colloidal particles	State of Medium	Name	Example
Gas	Liquid	Foam	Suds on beer or soapy water, whip cream, shaving cream, fire-fighting foam
Gas	Solid	Foam	Foam rubber, Styrofoam, marshmallows, Sponge, pumice
Liquid	Gas	Aerosol	Fog, clouds, aerosol sprays
Liquid	Liquid	Emulsion	Homogenized milk, mayonnaise
Liquid	Solid	Emulsion	Butter
Solid	Gas	Aerosol	Smoke, airborne particulates
Solid	Liquid	Sol	Cream, milk of magnesia, mud, detergents, paints, toothpaste, Jell-O
Solid	Solid		ruby glass

Further, colloids can also be classified as lyophilic or solvent loving and lyophobic or solvent hating. In case where the dispersion medium is water, the colloids are termed as hydrophilic or hydrophobic. One example of hydrophilic colloid is Gelatin.

As the concentration of dissolved particles is very low show any effect of vapor pressure of the solvent, no colligative properties are exhibit by the colloid mixtures. Anyhow, Tyndall Effects are exhibit by the colloidal solutions, which is the ability of a solution to scatter light to make the beam visible through the medium.

REVIEW QUESTIONS

1. How many grams of NaCl shall be dissolved in 100 g of water to get a solution of 3.46 mL in NaCl?
2. A solution is made by dissolving 2.275 g of NaOH in enough water to get a 200.0 mL solution. Find the molarity of the solution.
3. Measure the mass percent of the solute in a solution that has 19.5 g NH_4Cl in 485 g of water. Find the molality of the solution.
4. A solution is obtained by mixing 16.0 g of CH_3OH and 50.0 g of water. (a) What is the mass percent of methanol in the solution? (b) What is the mole fraction of each component in the solution? (c) If the density of solution is 0.955 g/mL, what is the molarity and molality of CH_3OH, respectively, in the solution?
5. The solubility of H_2S gas in water at 20°C and 1 atm pressure is 258 mL (measured at STP) per 100 g H_2O. (a) What is the mass percent of dissolved H_2S? (b) What is the molality of the H_2S solution? (c) What is the solubility of H_2S gas expressed in mL of H_2S (at STP) per 100 g H_2O when the temperature is 20°C and the partial pressure of the gas is 255 torr?
6. Benzene and toluene form an ideal solution at all proportion. The vapor pressure of pure benzene and pure toluene at 25°C are 95.1 and 28.4 mmHg, respectively. What is the vapor pressure of a solution that contains 50.0 g benzene (mw 78.11) and 50.0 g toluene (mw 92.13)? What is the composition of the vapor that is in equilibrium with the above benzene-toluene solution at 25°C?
7. Styrene (C_8H_8) and ethylbenzene (C_8H_{10}) form ideal mixture. If a mixture is composed of 38% styrene and 62% ethylbenzene, by mass, at 90^{o}C, what is the composition of the vapor in equilibrium with the liquid mixture? The vapor pressure of styrene and ethylbenzene at 90^{o}C are 134 mmHg and 182 mmHg, respectively.
8. A radiator fluid mixture contains 3.00 kg of antifreeze ethylene glycol ($C_2H_6O_2$) and 2.50 kg of water. What is the boiling and freezing points of the solution? (For water, K_f = 1.86°C/m; K_b

= 0.512°C/m)

9. What is the minimum concentration of ethylene glycol ($C_2H_6O_2$) solution that will protect the cooling system from freezing at 0.0^{o}C?

10. If a solution contains 10.5 g of sucrose ($C_{12}H_{22}O_{11}$) per 100 mL, what is its osmotic pressure at 25°C? What concentration (in g/100 mL solution) of salt (NaCl) would exhibit the same osmotic pressure? (Assume NaCl dissociates completely.)

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CHAPTER

4

ACIDS, BASES, AND SALTS

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- Arrhenius acid-base theory
- Bronsted-Lowry acid-base theory
- Chemical properties of acids and bases
- pH scale and its applications
- Different kind of salts

KEYWORDS

- Arrhenius Acid-base Theory
- Bronsted-Lowry Acid-Base Theory
- Olfactory Indicators
- Litmus Solutions
- Acids
- Bases
- Sulfites
- Metal Sulfites
- Metal hydrogen Carbonates
- Non-Metallic Oxides

4.1. INTRODUCTION

It's been ages that people believe that acids are present in lemon juice and vinegar juice and many other edible food items that taste sour. It has been only just a few hundred years to the discovery that acids taste sour and changes blue litmus red.

In Latin term *acere*, which means "**sour**." Bases are slippery to touch and changes red litmus blue. Acids and bases are defined in multiple ways and in the following chapter, the fundamentals of acid and base chemistry are discussed in detail.

Properties of Acids are:

- Acids reacts with bases and salt and water are obtained as a result.
- Acids produce salt and hydrogen gas on reacting with various metals.
- Salt, water and carbon dioxide gas are formed as a product of reaction of acid with **carbonate**.
- Acids turn blue litmus red.
- The acidic nature lies in the range of 0-6 on pH scale.

Properties of Bases are:

- It reacts with acids to form salt and water.
- It turns red litmus blue.
- The basic character lies in the range of 8-14 on pH scale.

Table 4.1: Naturally occurring acids

Orange –	Citric Acid
Vinegar –	Acetic Acid
Lemon –	Citric Acid
Tomato –	Oxalic Acid
Sour milk (Curd) –	Lactic Acid
Tamarind –	Tartaric Acid
Ant and Nettle sting –	Methanoic Acid (Formic acid)

4.2. ARRHENIUS ACID-BASE THEORY

4.2.1. Arrhenius Definition

Why all bases have similar properties and why all acids are similar is explained by Svante August Arrhenius in his theory. The reason to this was explained as all acids release H^+ (proton) or H_3O^+ (**hydronium ions**) in aqueous solution whereas, basic solutions release **hydroxide ions**, OH^- in aqueous solution.

Carbonate is a polyatomic anion with the formula CO_2^{-3} and has a trigonal planar molecular structure which consists of a carbon atom surrounded by three oxygen atoms.

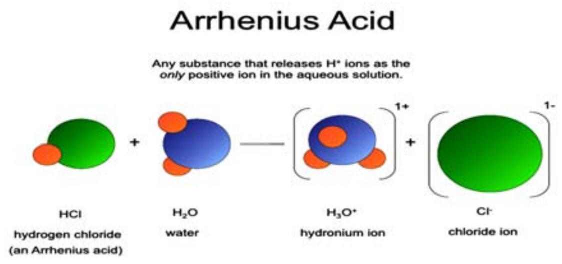


Figure 4.1: Arrhenius Acid-Base theory.

Source: https://www.slideshare.net/KevinCram/acids-and-bases-13142195

4.2.1.1. Arrhenius Acid

Arrhenius acid is defined as a substance which produces protons (H^+) or hydronium ion (H_3O^+) in aqueous solution. For example, NaOH is an example of Arrhenius Base.

4.2.1.2. Arrhenius Base

Arrhenius base is defined as a substance that forms hydroxide ion or OH^- in an **aqueous**

solution. For example, HCl is an example of Arrhenius Acid.

Aqueous solution is a solution in which the solvent is water. It is mostly shown in chemical equations by appending (aq) to the relevant chemical formula.

4.3. BRONSTED-LOWRY ACID-BASE THEORY

An alternative way to define acids and bases was given by Johannes Nicolaus Bronsted (Denmark) and Thomas Martin Lowry (England). Their definition came out as a solution to the challenges associated with non-hydroxide bases such as ammonia (NH_3), which could be explained by Arrhenius definition as a base limiting the acid base reactions to few reactions.

According to **Brønsted-Lowry**, acids and bases are defined as the substances which are able to donate and accept protons (H^+ hydrogen ion) respectively. Thus, acids and bases are treated as proton transfer agents.

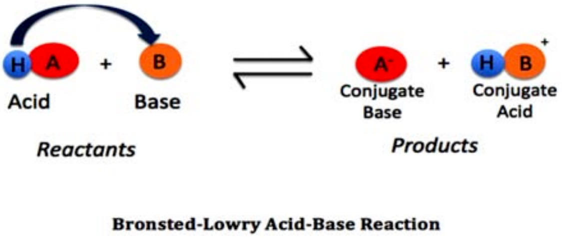


Figure 4.2: Bronsted-lowry acid-base reaction.

Source: https://study.com/academy/lesson/bronsted-lowry-acid-definition-examples.html

An acid is a "**proton donor**" while on other hand a base is a "**proton acceptor**." The use of hydronium ion (H_3O^+) instead of using proton (H^+) was proposed by Lowry. By comparing the proton donor ability of two different compounds (pure), he did highlight the fact that acidity is a relative concept. For example, hydrogen chloride only behaves like an acid when it is made to react with water.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

The chances of this reaction to move in *right* direction are high. In the above reaction HCl acts like a Brønsted-Lowry acid because HCl possesses a proton that will get transferred after the reaction, and H_2O acts as a Brønsted-Lowry base because it receives the proton that is lost by the Brønsted-Lowry acid.

4.3.1. Acid-Base Indicators

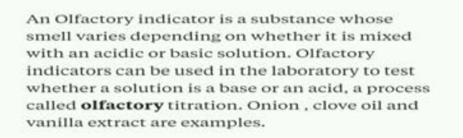
Indicators are chemicals or substances which when added to other chemicals (acids or bases), helps in determining the nature of chemical substances by changing the color.

4.3.2. Litmus Solution

This indicator is naturally occurring substance. Litmus is extracted from lichens and is a purple color dye. Some more examples of naturally occurring indicators are colored petals of turmeric and petunia and red cabbage.

4.3.3. Olfactory Indicators

These indicators change smell or odor in acidic or basic media, e.g., Onion, clove, vanilla extract, etc.



An Olfactory indicator is a substance whose smell varies depending on whether it is mixed with an acidic or basic solution. Olfactory indicators can be used in the laboratory to test whether a solution is a base or an acid, a process called **olfactory** titration. Onion , clove oil and vanilla extract are examples.

Figure 4.3: Definition of olfactory indicator.

Source: https://www.meritnation.com/ask-answer/question/pls-give-answer-quickly-q-3-what-are-olfactory-indica/chemical-reactions-and-equations/12755615

4.3.3.1. Acid-Base Indicators

Table 4.2: Indicators and Their Acidic and Basic Forms

S.No.	Name of the Indicator	Color Change in Acidic Medium	Color Change in Basic Medium
1.	Red litmus	No change	Turns blue
2.	Blue litmus	Turns red	No change
3.	Methyl orange	Turns red	Turns yellow
4.	Phenolphthalein	No change (colorless)	Turns pink
5.	Turmeric	No change	Turns red

Concentrated acids are those acids which are made using large amounts of acids and lesser quantities of water.

Whereas, dilute acids are those which are made using lesser quantity of acids and comprise of a major amount of water. The outcome is that fall in the concentration of OH^- or H_3O^+ per unit volume in bases and acids, respectively.

Precaution must be taken while mixing acid or base with water. While diluting an acid, acid must be added to water always slowly with constant stirring. If water is added to acid a highly **exothermic reaction** (releasing large amount of heat energy) take place which may cause the mixture to splash out and cause burns.

Exothermic reaction is a chemical reaction that releases energy through light or heat.

4.4. CHEMICAL PROPERTIES OF ACIDS AND BASES

Following chemical properties are shown by acids and bases:

4.4.1. Reaction of Bases and Acids with Metals

Metal + Acid → Salt + Hydrogen gas

Acids on reacting with metals leads to the formation of a salt as product and hydrogen gas are released. For example, metals like Zinc and Magnesium reacts with acids (like HCl or H_2SO_4) and displace hydrogen from acids in the form of hydrogen gas and the metal combines with the anion part of the acids and form a compound called salt.

$$\underset{\text{(zinc)}}{\mathrm{Zn}} \quad + \quad \underset{\text{(hydrochloric acid)}}{\mathrm{2HCl}} \quad \rightarrow \quad \underset{\text{(zinc chloride)}}{\mathrm{ZnCl_2}} \quad + \quad \underset{\text{(hydrogen gas)}}{\mathrm{H_2}}$$

Not all metals react with bases. There are only some metals which react with bases to liberate hydrogen gas. For example, Zinc metal reacts with sodium hydroxide to form sodium zincate as salt and hydrogen gas is evolved.

4.4.2. Reaction of Acids with Metal Hydrogen Carbonates and Metal Carbonates

Reaction of acids with metal hydrogen carbonates (also known as bicarbonates) and metal carbonates takes place salts and carbon dioxide and water as byproducts. Acids react with metal carbonates and metal hydrogen carbonates (also called bicarbonates) to form the respective salts, water, and carbon dioxide. Carbon dioxide gas liberated is marked with brisk effervescence.

Metal Carbonate + Acid → metal salt + water + carbon dioxide

The gas evolved is carbon dioxide can be confirmed by passing the gas released through freshly prepared lime water (Calcium Hydroxide). The limewater turns milky.

$$Ca(OH)_2 + CO_{2\,(g)} \rightarrow CaCO_3 + H_2O$$

$Ca(OH)_2$	$CO_{2\,(g)}$	$CaCO_3$	H_2O
Lime water	Carbon dioxide	Calcium carbonate	Water

4.4.3. Reaction of Bases and Acids with One Other (Neutralization Reaction)

Acids react with bases or bases react with acids to from salt and water. In all acid-base reactions both acids and bases lose their character. Thus, it can also be stated that their acidity and basicity is destroyed and thus, such a reaction is termed as **neutralization** reaction. Generally, a neutralization reaction can be represented as:

Neutralization is a chemical reaction in which an acid and a base react quantitatively with each other. In a reaction in water, neutralization results in there being no excess of hydrogen or hydroxide ions present in the solution.

Acid + Base → Salt + Water

For example, if the reaction of sodium hydroxide and hydrochloric acid is considered, it can be seen as

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$HCl_{(aq)}$	$NaOH_{(aq)}$	$NaCl_{(aq)}$	$H_2O_{(l)}$
Hydrochloric acid	Sodium hydroxide	Sodium chloride	Water

4.4.4. Reaction of Acids with Metallic Oxides

Acids on reacting with metallic oxides leads to the formation of corresponding salts and water and the reaction between the acids and metal oxides can be represented as:

Acid + Metal oxide → Salt + Water

For example: copper oxide reacts with hydrochloric acid to form copper (II) chloride as salt and water.

4.4.5. Reaction of non-metallic oxides with bases

Bases on reacting with non-metallic oxide like carbon dioxide to produce salt and water. For example, sodium hydroxide on reacting with carbon dioxide forms sodium carbonate and water.

$$2NaOH_{(s)} + CO_{2(g)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)}$$

Sodium hydroxide + Carbon dioxide → Sodium carbonate + Water

The base calcium hydroxide solution reacts with carbon dioxide to produce salt and water.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_{3(s)} + H_2O_{(l)}$$

Calcium hydroxide + Carbon dioxide → Calcium carbonate + Water

4.4.6. Reaction with Sulfites and Bisulfite (Or Hydrogen Sulfites)

Dilute acids on reacting with sulfites and bisulfite (or hydrogen sulfites) produces salt, water and sulfur dioxide.

Sulfite + Acid → Salt + Water + Sulfur dioxide

4.4.7. Reaction of Acid with Metal Sulfides

Acids on reacting with metal sulfides leads to the formation of salt and hydrogen sulfide gas are evolved. The gas evolved has a characteristic smell of rotten eggs.

Metal sulfide + Acid → Salt + Hydrogen sulfide

Some examples are given below:

- Acids or bases in a Water Solution

In the presence of water or in aqueous solution, acids release H^+ ions. The H^+ ion is enabling to exist alone, therefore it exists as H^+ (aq) or as hydronium ion (H_3O^+).

For example,

$HCl + H_2O \rightarrow H_3O^+ + Cl^-$

$H^+ + H_2O \rightarrow H_3O^+$

In the presence of water or aqueous solution, the bases produce hydroxide ion (OH^-).

- Alkalis

All bases are not soluble in water. But there are some bases which dissolve in water. Such water-soluble bases are referred to as alkalis. Therefore, it can be states that, all bases are not alkalis but all alkalis are bases. Some commonly used alkalis are:

- KOH – Potassium hydroxide
- NH_4OH – Ammonium hydroxide
- $NaOH$ – Sodium hydroxide
- $Ca(OH)_2$ – Calcium hydroxide

4.5. PH SCALE

In 1909, the Danish biochemist, Soren Peter Lauritz Sorenson, advised a new term for expressing the hydrogen ion concentration called pH or pH scale. The term pH originated from the German word “potenz” which means power or strength and H is the element symbol of hydrogen. Therefore, pH is an abbreviation for “power of hydrogen.”

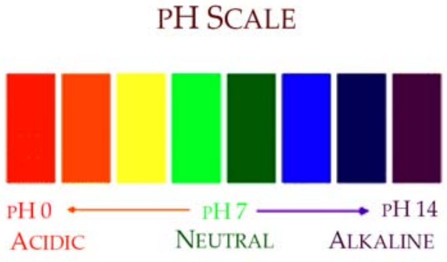


Figure 4.4: pH scale.

Source: https://www.mommyconnections.ca/blog/2016/03/22/quick-and-easy-skin-care-tips/ph-scale/

Chemical properties and characteristics of chemicals are being confined in between two extremes known as acids and bases. One way to neutralize or cancel the extreme impact or effect of bases and acids is to mix them with each other. The final product obtained after this is a substance that is neither an acid nor a base in nature and is known a **neutral substance**.

Neutral substance is a substance that shows no acid or base properties, has an equal number of hydrogen and hydroxyl ions and does not change the colour of litmus-paper.

The main usage of pH scale is seen in measuring the acidity and basicity of a given substance. The range of pH scale is between 0 and 14, where pH 7 is considered as a neutral. Substances having values less than 7 on a pH scale are acidic in nature while substances with pH value greater than 7 are basic in nature. Another interesting fact about pH scale is that it is logarithmic in nature and hence, every complete value of pH that is below 7 is considered 10 times more acidic as compared to the next higher value.

Considering an example, the value of pH 3 is ten times more acidic as compared to a value of pH 4, and further, it is 100 times i.e., ten times ten, more acidic as compared to value of pH 5. The same trend is followed in case of basic solutions, that is pH values greater than 7, i.e., every whole value of pH is considered ten times more basic or alkaline as compared to the next full value. Considering an example, pH value of 11 is 10 times more basic (or alkaline) as compared to pH value of 10 and 100 times (ten times ten) more basic as compared to the pH value of 9. Greater is the value of pH, higher will be the basic character. Lower will be the value of pH, stronger will be the acidic character of the solution. On the pH scale, pure water is neutral in nature, that is, it has a pH of 7. Further, when various compounds are added to the water, the obtained mixture can become either basic or acidic, depending upon the properties of the added compound. For example, some of the basic substances are ammonia, milk of magnesia (magnesium hydroxide) and lye (sodium oxidanide), while some examples of acidic substances are lemon juice and vinegar.

4.5.1. Importance of pH in Our Digestive System

pH level of our body regulates our digestive system. In case of indigestion a large amount of acid is produced by our stomach. Production of acid in large quantity causes pain and irritation in stomach or burning sensation in stomach. This condition is generally referred as acidity.

In order to get rid of this pain antacids are used. The nature of these antacids is basic; therefore, they neutralize the acids in our stomach and we get relief. Milk of Magnesia is an example of commonly used antacid.

pH of Acid Rain

Rain water possessing a pH value of 5.6 is referred as Acid Rain. When the water of this acid rain falls on earth, causes a lot of damage. Taj Mahal, one of the Seven Wonders of the World, saw its effect in recent years. The pure white marbles of this historical monument were becoming yellowish. Also, the water of acid rain goes into rivers and lakes making the water polluted and thus, bringing a major threat to the aquatic life form.

pH of Soil

For healthy growth, plants need pH value of specific range. The pH of soil of any particular place is either less or greater than the required range or value then suitable fertilizers are added.

Human bodies are functional only in a narrow range of pH 7.0 to 7.8 and this is a challenge for us to survive as this make humans more prone to minor chemical changes in surroundings. This minute changes have a severe impact on health of the humans.

Tooth Decay and pH:

Consumption of a lot of sweet or sugar containing food general sticks or is left behind in the mouth, if not rinsed properly. Slowly and gradually the sugar and other food particles starts degrading by the action of the bacteria present in our mouth and acid is produced. This may result in cavities and foul smell from mouth and finally tooth decay. This acid produced in our mouth can be neutralized by the bases present in toothpaste. Brushing twice a day is important so as to prevent tooth decay.

Methanoic acid is the simplest of the carboxylic acids, used in processing textiles and leather.

Bee sting or Nettle sting contains **methanoic acid** (also called as formic acid), which causes pain and irritation. By rubbing a weak base like baking soda on it we get relief.

4.6. SALTS

A compound formed as a reaction between an acid and a base (neutralization reaction) is called as salt.

$$\text{Acid} + \text{Base} \rightarrow \text{Salt} + \text{Water}$$

For example,

$$\underset{\text{Hydrochloric Acid}}{HCl_{(aq)}} + \underset{\text{Sodium hydroxide}}{NaOH_{(aq)}} \rightarrow \underset{\text{Sodium chloride}}{NaCl_{(aq)}} + \underset{\text{Water}}{H_2O}$$

A salt is an ionic compound that consists of a negative ion or anion in place of hydroxyl ion and a cation or a positive ion in place of hydrogen.

The classification of salts:

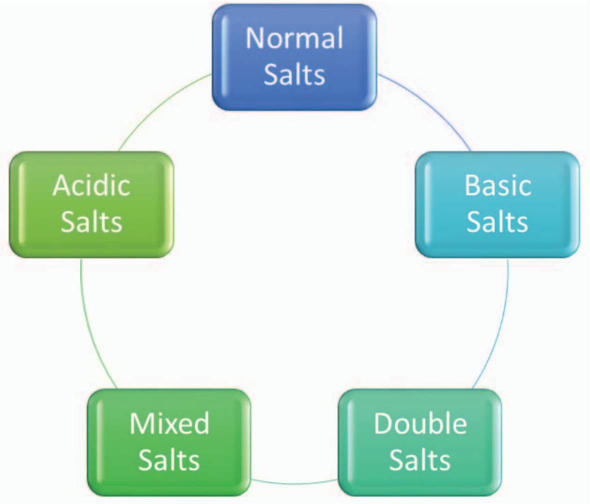


Figure 4.5: Classification of salts.

1. Normal Salts:

A salt which do not have any replaceable or ionizable atoms of hydrogen in its molecule are classified as normal salts. Commonly the normal salts are created by total substitution of all the atoms of hydrogen of an acid that can be replaced by the electropositive radical or metallic for example ammonium ion. Some of the examples of common salts are sodium chloride, or NaCl is obtained when the hydrogen atom from HCl or hydrochloric acid is replaced by the sodium metal ion.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

In the same way, a normal salt sodium sulfate is obtained by replacing both of the hydrogen atoms of H_2SO_4 by sodium metal atoms.

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

2. Acidic Salts:

Salts that are formed by partial substitution of replaceable hydrogen ion are classified as acidic salts. These salts consist of replaceable hydrogen ions.

For example,

$$H_2SO_4 + NaOH \rightarrow NaHSO_4 + H_2O$$

In the above example, the sodium metal displaces only one hydrogen ion from the acid Sulfuric acid. Further, the acid salts on reacting with bases result in the formation of normal salts. This because these salts consist of **hydrogen ion**.

Hydrogen ion is the cation H+ of acids consisting of a hydrogen atom whose electron has been transferred to the anion of the acid.

3. Basic Salts:

The salts produced as a result of partial neutralization of a base by an acid are classified as basic salts.

For example,

$$Cu(OH)_2 + HCl \rightarrow Cu(OH)Cl + H_2O$$

Copper Hydroxide Base	Hydrochloric acid	Basic copper chloride

Further, the basic salts on reacting with acids produce normal salts.

Some more examples of basic salts are given below:

$Pb(OH)NO_3$, $Pb(OH)Cl$, $Cu(OH)NO_3$

4. Mixed Salts:

The salt which furnishes more than one cation or more than one anion when dissolved in water is called mixed salt.

Few more examples of mixed salts are: $NaNH_4HPO_4$ (microcosmic salt), $NaKCO_3$.

5. Double Salts:

The salts are formed by two simple salts in their equimolar proportions when they are gradually started to crystallize from a mixed compound made from their salt solution that is saturated in nature.

For example: K_2SO_4, potash alum, $24H_2O$, $Al_2(SO_4)_3$ is obtained by the mix of $Al_2(SO_4)_3$ and K_2SO_4 as per the molar ratios in the water solution after which the **crystallization** process takes place.

Crystallization is the process by which a chemical is converted from a liquid into a solid crystalline state.

Some other examples of double salts are:
$(NH_4)_2 Fe(SO_4)_2.6H_2O$ Mohr's Salt
$K_2SO_4Fe_2(SO_4)_3.24H_2O$ Ferric alum

4.7. PH OF SALTS

The nature of the salt, i.e., whether they are acidic, basic or neutral is marked by the acid or base from which they are produced. Thus, the pH value of the salts varies.

Generally, it can be considered that:

- The salts obtained by the reaction taking place between a strong base and a strong acid are neutral, i.e., with a pH value of 7. For example: KNO_3, NaCl.
- The salts obtained by the reaction taking place between a weak base and a strong acid are acidic and has a pH value less than 7. For example:

$CuSO_4$, NH_4Cl.

- The salts are obtained due to the reaction of a strong base and a weak acid are basic and has a pH value of greater than 7. For example: Na_2CO_3.

(1) Common Salt (or Sodium Chloride)

Common salt is a compound consisting of elements sodium and chlorine.

Occurrence: Seawater consists of many salts in it. Common salt is derived from seawater. At certain places the salt is mined like coal from salt rock.

Chemical Formula: NaCl

Properties:

- Common salt is deliquescent. It means it has ability to absorb moisture. This happens because of the availability of magnesium chloride ($MgCl_2$) in it.
- Common salt is thermally very stable.
- Common salt dissolves in water completely. The solubility of NaCl increases with the increase in temperature.

Uses:

Being cheap common salt or sodium chloride is a chemical compound of great use. It is used widely for various purposes given below:

- It is an important food ingredient.
- It has a great application as a preservative for fish or meat.
- It has applications in freezing of substances (mixes that contains solid granular common salts and ice) that

produce low temperature.

- Common salt is used majorly in the production of a huge variety of useful compounds for example, baking soda, caustic soda, chlorine gas, soda ash (washing soda), hydrochloric acid, etc.
- It has an extensive use in the soap production industry.

Some common examples of compounds derived from common salts are:

- Sodium hydroxide.
- Bleaching powder.
- Baking soda.
- Washing soda.

4.7.1. Sodium Hydroxide, NaOH

When electricity is passed through an aqueous solution of sodium hydroxide (also called as brine), it decomposes to form sodium hydroxide. During the process of **electrolysis**, product obtained at anode is chlorine gas whereas the product formed at cathode is hydrogen gas.

Electrolysis is a technique that uses a direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction.

Sodium hydroxide is formed near cathode. This process is referred to as color-alkali process because of the formation of chlorine gas and an alkali sodium hydroxide as product.

$$NaCl_{(aq)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + Cl_{2(g)} + H_{2(g)}$$

It also has applications in the production of paper, soaps, detergents, a number of chemicals and artificial silk.

4.7.2. Bleaching Powder

Chemical name: Calcium oxychloride

Chemical formula: $CaOCl_2$ or $Ca(OCl)Cl$

Preparation:

When chlorine gas is passed over dry slaked lime, bleaching powder is formed.

- Bleaching powder is a yellowish white powder and possesses a strong smell of chlorine.
- Bleaching powder dissolves in cold water completely producing a milky solution due to free lime present in it.
- Reaction with carbon dioxide.

On exposing the bleaching powder to air, it deteriorates releasing chlorine. This is due to the fact that on reacting with carbon dioxide available in air it produces chlorine gas and calcium carbonate as products.

$$CaOCl_2 + CO_2 \rightarrow CaCO_3 + Cl_2$$

Calcium Carbon Calcium Chlorine
oxychloride dioxide carbonate
(from air)

Reaction with dilute acids:

On treating the bleaching powder with excess of dilute acid such as HCl or H_2SO_4 all the chlorine present in it is liberated. The liberated chlorine is used for bleaching the cloth.

$$CaOCl_2 + 2HCl \rightarrow CaCl_2 + H_2O + Cl_2$$

Calcium Calcium oxychloride chloride

Applications of bleaching powder:

- Bleaching powder finds a great deal of usage in sterilizing water.
- Bleaching powder is an excellent oxidizing agent and is used extensively

in industries all over the world.

- For the purpose of bleaching it is used in wood pulp in paper industry and in textile industry for bleaching the cotton fabrics or fiber.
- Bleaching powder is an effective and economical germicide and disinfectant.

4.7.3. Washing Soda

Chemical name: Sodium carbonate decahydrate

Chemical formula: $Na_2CO_3.10H_2O$

In commercial terms, anhydrous sodium carbonate (Na_2CO_3) is also known as soda ash.

Preparation:

Solvay process (also referred as ammonia soda process) is implemented in producing the sodium carbonate. The process is described below:

- When carbon dioxide gas is passed over the brine solution (about 28% NaCl), saturated with ammonia, it produces sodium bicarbonate.

$$NaCl + H_2O + NH_3 + CO_2 \rightarrow NaHCO_3 + NH_4Cl$$

Sodium Sodium chloride bicarbonate (ppt)

The precipitate of sodium bicarbonate is dried and filtered. It is ignited to give sodium carbonate:

$$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$$

Sodium

carbonate

Properties:

- Washing soda dissolves completely in

water. An alkaline solution is obtained when washing soda is dissolved in water. This solution turns red litmus paper into blue, which proves that this aqueous solution is alkaline in nature.

- Other important property of washing soda is that its physical appearance is transparent crystalline solid. It is found as a decahydrate, i.e., $Na_2CO_3.10H_2O$ that consists of 10 molecules of water of crystallization.
- On leaving the washing soda openly in the air or exposing it to atmosphere, allows a loss of nine molecules of water of crystallization and results in the formation of white powder of sodium carbonate monohydrate. This process witnessing the loss of water of crystallization from its hydrated salt to air, when kept exposed to air is referred to as efflorescence. Therefore, washing soda is **efflorescent**.

Efflorescent is the migration of a salt to the surface of a porous material, where it forms a coating.

$$\underset{\text{Sodium carbonate Decahydrate}}{Na_2CO_3.10H_2O} \rightarrow \underset{\text{Sodium carbonate (monohydrate)}}{Na_2CO_3.H_2O} + 9H2O$$

Effect of heat:

Washing soda does not decompose on heating at a temperature above 373K instead it forms an anhydrous salt by losing all its water of crystallization. Thus, the monohydrate salt turns anhydrous completely and gets converted to white powder called soda ash.

Applications of Sodium Carbonate or Washing Soda

Some of the majorly implemented applications of Washing Soda are mentioned below:

- Washing Soda or Sodium Carbonate is extensively used as raw material in producing some important chemical compounds like borax.
- It is extensively used in the production of detergent and in softening of hard water.
- It has a major application in laundry and in washing clothes.
- Sodium carbonate is also having many applications in paint and paper industries.

4.7.4. Baking Soda

Chemical Name: Sodium bicarbonate or Sodium hydrogen carbonate

Chemical Formula: $NaHCO_3$

Manufacture:

Artificially, the preferred way to produce sodium bicarbonate in the laboratory is by saturating a cold solution of sodium carbonate and carbon dioxide together.

$$\underset{\text{Sodium carbonate}}{Na_2CO_3} + \underset{\text{Carbon dioxide}}{CO_2} + H_2O \rightarrow \underset{\text{Sodium bicarbonate (white crystals)}}{2NaHCO_3}$$

Sodium hydrogen carbonate is less soluble, therefore is separated out as white crystals.

Properties:

- Sodium bicarbonate is a mild non-corrosive base and is a white crystalline solid.

- It dissolves completely in water and forms an aqueous solution which is alkaline in nature possessing a pH value greater than 7. Thus, it is used to neutralize an acid.
- Effect of heat:

When sodium hydrogen carbonate is heated it gets converted into sodium carbonate accompanied by the release of carbon dioxide gas.

$$\underset{\text{Sodium bicarbonate}}{2NaHCO_3} \rightarrow \underset{\text{Sodium carbonate}}{Na_2CO_3} + CO_2 + H_2O$$

Applications of sodium bicarbonate

Some major uses of sodium bicarbonate are given below:

- Sodium bicarbonate is extensively used in fire extinguishers especially the old type ones.
- Sodium bicarbonate is a good antacid and used in neutralizing the burning effect of acids release in stomach and reduces acidity.
- It finds a great deal of application in preparation of effervescent drinks and baking powder.

What is baking powder?

Baking powder is basically a mixture of sodium hydrogen carbonate and an acidic compound like citric acid or potassium hydrogen tartrate.

Is has wide applications in preparation of fluffy, porous cakes and breads. During the preparation of bread or cake, a reaction occurs between sodium hydrogen carbonate and the acidic compound, releasing carbon dioxide. The liberated carbon dioxide makes the bread or cake fluffy or porous, i.e., soft and light in weight.

Plaster of Paris

Chemical Name: Calcium sulfate hemihydrate

Chemical Formula: $CaSO_4.½\,H_2O$ or $(CaSO_4)2.H_2O$

Manufacture:

On heating gypsum ($CaSO_4.2H_2O$) at 373 K, it loses water molecules and becomes calcium sulfate **hemihydrate**. This is called Plaster of Paris.

Hemihydrate is a hydrate whose solid contains one molecule of water of crystallization per two molecules, or per two unit cells.

$$\underset{\text{Gypsum}}{CaSO_4.2H_2O} \rightarrow \underset{\text{plaster of Paris}}{CaSO_4.\,½\,H_2O} + 3/2\,H_2O_{(g)}$$

Properties:

- Plaster of Paris is a white colored powder that absorbs water accompanied by the release of heat.
- Plaster of Paris has a unique property of setting as a hard mass when mixed with water. This is termed as setting of plaster of Paris. This happens as a result of the hydration into gypsum. Therefore, it is advisable to store Plaster of Paris in moisture proof container.

$CaSO_4$. ½ H2O + 1 ½ H_2O → $CaSO_4.2H_2O$
plaster of Paris Gypsum

Applications of Plaster of Paris

- Plaster of Paris is used in manufacturing of chalks for writing on black board.
- Sealing air gaps.
- Plaster of Paris finds application in medical field as it is used in plasters for fractured bones so the broken bone or joint is kept in a fixed place.
- Making molds for toys, statues and other decorative objects.

Water of Crystallization

Water of crystallization is also known as water of hydration in chemical terms. They are seen as the molecules of waters that are present in the molecule. It is a particular number of water molecules that are found in one unit of salt. The main source of water is the aqueous solutions that are used during the formation of crystals.

It is general that many compound incorporate water molecules in their structure (crystalline framework), specifically the cases where the solvent is water or other liquid. It is easy to remove the water of crystallization by simply heating the sample but due to the heating, some of the properties of sample are often lost such as the dihydrate of sodium chloride found to be unstable at room temperature. For example, ten molecules of water are found in one unit compound of washing soda. Similarly, five molecules of water are there in one unit compound of copper sulfate, so the chemical formula of hydrated copper sulfate is $CuSO_4.5H_2O$.

REVIEW QUESTIONS

1. Name the sodium compound used for softening the hard water.
2. What is a neutralization reaction? Give one example.
3. Name any two natural indicators.
4. What is baking powder? Give its one application.
5. How does an acid react with sodium carbonate or bicarbonate?
6. What is the confirmatory test to check the evolution of carbon dioxide gas?
7. The pH value of compounds A, B, C, D are 6, 9, 2, 11, respectively. Arrange them in the increasing order of their hydrogen ion concentration.
8. Why plaster of Paris should be stored in moisture proof container?
9. What happens when a piece of zinc metal is dropped in HCl solution? Write the chemical equation involved.
10. What is the name given to the process of electrolysis of brine? Why it is called so?

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CHAPTER

5

THE STATES OF MATTER

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- The different states of mater
- Intermolecular forces and thermal interactions
- Transitions of states of matter
- The kinetic molecular theory of matter
- Charles' law and its application

KEYWORDS

- States of Matter
- Liquid
- Gaseous State
- Solid
- Thermal energy
- Boyle's Law
- Kinetic Molecular Theory
- Viscosity
- Charles' Law
- Vapor Pressure
- Volume

5.1. INTRODUCTION

Matter can be a befuddling word since it has a few implications. We frequently hear phrases like “What is the matter?” or “It doesn’t matter.” Scientists have a different understanding of the word “matter.” According to them it is whatever consume space and has mass.

The three states of matter – solid, liquid, and gas – vary principally in two regards: a) The separation between the ions or molecules, and b) the degree to which the ions or molecules move. In the solid and liquid states, the ions or molecules are extremely close, while in the gaseous state, these particles are isolated by moderately vast separations.

Almost all substances on earth can exist in one of the three states that are given as solid, liquid and gas. These are the three most common forms in which matter is found. The decision on whether a substance is solid, liquid or gas, rests on the temperature the substance is existing in and the pressure that it is experiencing.

For instance, at normal room temperature, which is given as 22°C, accompanied by a normal atmospheric pressure that is being exerted on it at that time, water can be found in liquid state that enables it to flow from one place to another.

But in case that the temperature is brought down to –0.01°C, water changes its state from liquid to solid as it turns to ice. And if the temperature is risen beyond 100°C, water changes its form from liquid to gas, as it gets converted to steam.

The alterations can be brought about by transforming the pressure by keeping the temperature same. This can be explained by the means of a phase diagram that shows the three states of matter and the phase change between them. Catering to so much information, the phase diagrams are formed for several substances.

In the solid state, the ions or molecules don’t interpret; that is, they move around inside the unbending structure that compels them. These particles do, nonetheless, vibrate about their positions. In the liquid and solid states, the particles are allowed to decipher.

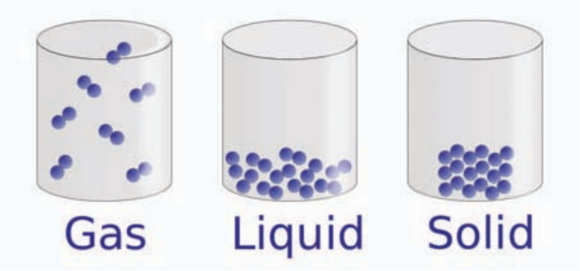

Figure 5.1: States of matter.

Source: https://zh-min-nan.wikipedia.org/wiki/t%C3%B3ng-%C3%A0n:States_of_matter_En.svg

The characterizing qualities that decide state incorporate the number and chemical makeup of the molecules and how a specific gathering of them is represented by such physical properties as their aggregate volume and shape, their response to temperature, and their response to weight.

The solid-state of the matter is portrayed by a fixed shape that is subject to the number and qualities of the particular atoms and molecules that make up the solid-state. The solid-state opposes change fit as a fiddle because of outside pressure.

To an exceptionally little degree with respect to different states, the density (mass/volume) of solids is dependent on temperature. Solids can be crystalline, which implies they have in all respects organized the structure to the particles that make up the solid, or the solid can be indistinct and have no symmetry in the setup of the particles that make up the solid.

In the liquid state, the matter will stream to take the state of any compartment. The density of the liquid is essentially subject to temperature, yet bound liquids oppose change because of pressure. The gaseous state likewise will take the shape of a compartment yet varies from liquids, in that it will extend to fill any compartment so that if the size of the container is expanded, the gas will grow to fill it.

Temperature, pressure, and the number of molecules is exceptionally significant parameters in characterizing the volume of a gas. Distinctive gases are in every case totally miscible (mixable), yet different liquids are not every time miscible.

The term phase is utilized in specific settings as opposed to the state to portray the physical properties of matter. A phase is a more confining term that is usually utilized in scientific studies; however, it is frequently utilized in normal discussions.

Where phase varies from the state can best be comprehended in depicting liquid mixtures, for example, oil and water. Each physically and chemically distinct and divisible liquid corresponds to a separate phase. The individual substances, similar to the mixture, are in the liquid state.

Plasma is a state of matter in which an ionized gaseous substance becomes highly electrically conductive to the point that long-range electric and magnetic fields dominate the behaviour of the matter.

Plasma is known as the fourth state of matter. Rarely on Earth's surface, however, 90% of the matter in space is in the plasma state. **Plasma** occurring naturally make up the ionosphere, a layer of low-density charged particles in the upper environment of Earth.

The plasma state is like the gaseous state, with the exception of it doesn't contain atoms and molecules. Rather, plasmas comprise of subatomic particles, for example, negatively charged electrons and positive ions. The matter is comprised of minor particles. These can be atoms or gatherings of atoms called molecules. Atoms resemble singular LEGO squares. They are the littlest unit that anything can be separated into without accomplishing something outrageous (like hitting a LEGO block with a sledge or crushing atoms in the Large Hadron Collider.) If atoms resemble LEGO squares, molecules are the structures you construct with them. The physical attributes of atoms and molecules choose the form or express the matter is in.

5.2. INTERMOLECULAR FORCES

Intermolecular forces are the powers of gravitation and revulsion between interconnecting particles (atoms and molecules). This term does exclude the electrostatic forces that exist between the two oppositely charged particles and the powers that hold atoms of a molecule together i.e., covalent bonds. Alluring intermolecular forces are known as van der Waals forces, out of appreciation for Dutch scientist Johannes van der Waals (1837–1923), who clarified the deviation of real gases from the perfect conduct through these forces.

We will find out about it later in this unit. van der Waals forces fluctuate impressively in size and incorporate scattering forces or London forces, **dipole-dipole forces**, and dipole-induced dipole forces. An especially strong sort of dipole-dipole connection is hydrogen bonding. Just a couple of components can take part in the formation of a hydrogen bond, because of these, it is treated as a different category.

Dipole-dipole forces are attractive forces between the positive end of one polar molecule and the negative end of another polar molecule.

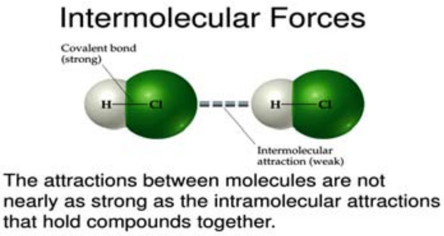

Figure 5.2: Intermolecular forces.

Source: https://www.slideserve.com/luella/intermolecular-forces

In the accompanying depiction, the term particle will be utilized to allude to an atom, molecule, or ion. Note that we will utilize the popular phrase "intermolecular attraction" to allude to attractive forces between the particles of a substance, paying little respect to whether these particles are molecules, atoms, or ions.

Consider these two features of the molecular-level environment in solid, liquid, and gaseous matter:

Particles in a solid-state are firmly pressed together and frequently orchestrated in a regular pattern; in a liquid, they are near one another with no normal setup; in a gas, they are far separated with no standard setup.

Particles in a solid-state vibrate with fixed positions and don't normally move in connection to each other; in a liquid, they move past one another however stay in basically steady contact; in a gas, they move autonomously of each other with the exception of when they hit.

The distinctions in the properties of a solid, liquid, or gas mirror the qualities of the alluring forces between the atoms, molecules, or ions that makes up each phase. The phase in which a substance exists relies upon the general degrees of its intermolecular forces (IMFs) and the kinetic energies (KE) of its molecules.

IMFs are the different alluring forces that may exist between the atoms and molecules of a substance because of electrostatic phenomena, as will be described in detail in this module. These forces serve to hold particles near one another, though the particle's KE gives the vitality required to defeat the appealing forces and, in this manner, increment the separation between particles.

At the point when gaseous water is cooled adequately, the allurement between H_2O molecules will be equipped for holding them together when they come into contact with one another; the gas gets consolidated and forms liquid H_2O. For instance, liquid water forms outwardly of a cold glass as the **water vapor** noticeable all around is cooled by the cold glass.

We can likewise melt numerous gases by compacting them if the temperature isn't excessively high. The expanded pressure brings the molecules of a gas nearer together, with the end goal that the attractions between the molecules become strong in respect to their KE. Thusly, they structure liquids. Butane, C_4H_{10}, is the fuel utilized in disposable lighters and is a gas at standard temperature and pressure. Inside the lighter's fuel compartment, the butane is packed to pressure those outcomes in its build-up to the liquid state.

5.3. THERMAL ENERGY

Water vapor can be produced from the evaporation or boiling of liquid water or from the sublimation of ice.

Thermal energy is the energy of a body emerging from the movement of its atoms or molecules. It is straightforwardly relative to the temperature of the substance. Thermal energy can be called a measure of average Kinetic energy of the particles of the matter and therefore results in movement of particles. This movement of a particle is known as thermal motion.

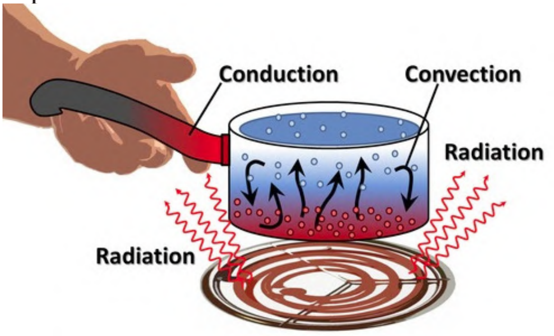

Figure 5.3: Thermal energy.

Source: http://www.deanalegassick.com/thermal-energy.html

5.4. INTERMOLECULAR FORCES VS. THERMAL INTERACTIONS

Chemical substances exist in various physical states – solid, liquid and gas. Let us take the case of H_2O. It exists as water, ice and steam. We realize that when it experiences an adjustment in the state, it is just a physical change. Its chemical properties don't transform; it is as yet a similar H_2O molecule. However, the rate at which the chemical reactions happen results in the changes with the physical state.

So, to comprehend the chemistry of the

reactions, we should know how the conduct of substances changes with the adjustment in their physical states. For this, we should know how the intermolecular-forces and thermal interactions influence the substance.

- Inter-molecular force is the alluring force acting between neighboring molecules. While we measure thermal energy as the addition of the Kinetic energy of the individual molecules and particles. So, the inter-molecular force of attraction keeps the particles together while the thermal interactions (kinetic energy) make them move separated.
- Let us state that under standard conditions, a substance X is solid. At this stage, the inter-molecular forces rule over the thermal energy of the particles. Therefore, the particles stick together and take up the solid state.
- When a substance is to be changed over from its gaseous state to a solid state, it's thermal energy (or temperature) must be diminished. On decreasing the thermal energy, the particles lose their Kinetic energy and therefore, the molecules stick together denoting the strength of inter-molecular forces.
- Similarly, if a gas is to be condensed, diminishing its thermal energy by lessening the temperature can do the needful.

Consequently, the presence of the diverse states of matter is only harmony between its inter-molecular forces and the thermal interactions between the particles. The power of inter-molecular forces is the least in gases and most in the solids; the transcendence of **thermal energy** is the least in solids and the most in gases.

Thermal energy comes from a substance whose molecules and atoms are vibrating faster due to a rise in temperature.

5.4.1. The Gaseous State

The volume of a given mass of a gas relies on the temperature and pressure under which the gas exists. It is, in this manner, conceivable to depict the conduct of gases as far as the four variables: temperature T; pressure P; volume V and amount (number of moles, n).

For a given measure of gas the volume of gas changes with change in variables, for example, temperature and pressure. The connection between any two of the variables is examined, keeping the other variable consistent by different laws, which are depicted underneath.

5.4.2. Effect of Pressure on the Volume of the Gas (Boyle's Law)

The effects of pressure on the volume of gas for a given measure of gas at steady temperature was examined by Robert Boyle in 1662 for various gases. He saw that if the volume of gas is increased twice then the pressure becomes half and the other way around. Boyle's law expresses that at a steady temperature, the volume of a given measure of gas is conversely relative to its pressure.

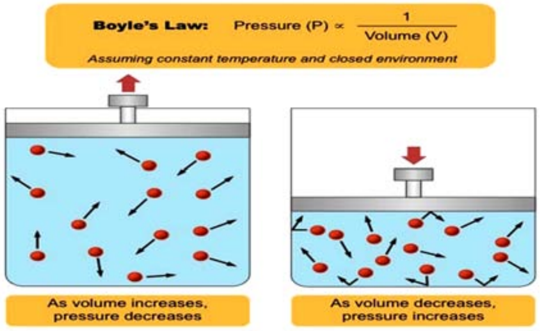

Figure 5.4: Boyle's law.

Source: https://ib.bioninja.com.au/standard-level/topic-6-human-physiology/64-gas-exchange/mechanism-of-breathing.html

5.5. TRANSITION OF STATES OF MATTER

Under certain conditions, the matter can be transformed from one state to another. But it is important to understand some of the terminology before we discuss those conditions:

- Melting point: the specific temperature at which matter transforms itself from solid to liquid.
- Boiling point: the specific temperature at which the pressure of vapor of liquid equals the atmospheric pressure. Water starts boiling at 100°C.
- Freezing point: the specific temperature at which matter transforms itself from fluid to solid.
- Evaporation: the specific temperature at which matter transforms itself from liquid to gas.

- Condensation: the specific temperature at which matter transforms from gas to liquid.

5.5.1. Measurable Properties of Gas

There are some properties of gases that help us in understand the transition as mentioned below:

1. It is represented in units of kg or grams.
2. The volume is represented in milliliters, centimeter, liters, cube, decimeter cube or meter cube.
3. Pressure is represented with the help of a barometer or manometer.
4. Temperature can be represented on Kelvin or Celsius scale. The equation for conversion is

T (K) = T (°C) + 273.15

5.6. THE KINETIC MOLECULAR THEORY OF MATTER

5.6.1. The Assumptions that we make for the Kinetic Molecular Theory

1. Matter is made up of tiny particles like molecules, atoms and ions.
2. These tiny particles (atoms, molecules or ions) are in random and constant motion and have some kinetic energy.
3. Due to intermolecular attraction, these particles also have some potential energy.

4. The Kinetic energy is directly proportional to the temperature as it increases with the rise in temperature.
5. At constant temperatures, total energy of the system always remains constant, but can be transferred from one particle to another during collisions.

Kinetic energy of the particles is linked with the motion of the particles, i.e., KE = ½mv^2. If the two particles that have dissimilar masses moves with the same speed, the particle with more mass will possess more kinetic energy. And on the other hand, if the particles of same masses are moving at a different speed, the particle moving fast will have the higher kinetic energy.

Kinetic energy is a property of a moving object or particle and depends not only on its motion but also on its mass.

Potential energy can be considered reverse of Kinetic energy as it is generated when two particles attract each other. Further, potential energy can be possessed by the particles that are under the influence of electrical or gravitational forces. In a molecule, atoms have potential energy as they attract each other. Cohesive forces are generated by potential energy in matter due to which particles are attracted to each other, forming solids and liquids. Kinetic energy gives rise to disruptive forces in matter that causes molecules to spread and create gases.

The state in which any substance exists is based on the relative strength of the cohesive forces or potential energy that is responsible for holding the particles together and the disruptive forces or kinetic energy which is responsible for scattering them.

Factors like temperature plays a very important role in identifying the state of the matter as Potential energy is dependent on factors like structure, molecular size along with the inherent properties of the molecules while it is completely independent on the temperature. Whereas, on the other hand, kinetic energy is dependent on the temperature as it is known that molecules move faster at high temperatures.

5.6.2. States of Matter: Solids, Liquids, and Gases

Solids have particular shapes and defined volumes because the particles in solids occupy a particular position in the crystal lattice structure. Due to the high cohesive forces, the particles, i.e., atoms, ions or molecules are kept in a fixed place. This results in a very little empty space between the molecules due to which solids have very low thermal expansion and compressibility. Solid materials possess high density that is merely affected with the temperature variations.

In liquids, cohesive forces are somewhat stronger as compared to disruptive forces. Particles are loosely packed, allowing some degree of freedom for translational motion, sliding freely over one another, thus, making liquids behave like fluid. Like solids, liquids have very low compressibility and thermal expansion; their densities vary only minutely with temperature.

On the contrary, gas particles have more kinetic energy than that of potential energy. Gaseous particles have been more free to move into the space and the motion of particles is independent of each other. The distance between the particles is much larger than the size of the particles. The speed and kinetic energy are directly proportional to the temperature and increases with temperature. As the outcome, a large volume is occupied by the gases. The gases expand largely with the rise in temperature and is highly compressible in nature. The density of gases is very low and is highly dependent on the pressure and temperature.

5.7. THE CHARLES' LAW

Charles' law was given in the 1700s by a French physicist named Jacques Alexandre Cesar Charles. According to Charles' law, "if the pressure of a gas is held constant, increasing the temperature of the gas increases its volume."

The question arises that what will happen when a gas is exposed to high temperature? The answer is its particles will gain energy. With rise in energy of the particles, they will attain a higher speed. Hence, the particles will move more and spread out farther. With this, the volume of gas increases and occupies more space.

Charles' Law states that "the volume of a given mass of gas varies directly with the absolute temperature of the gas when pressure is kept constant." The absolute temperature is temperature measured on the Kelvin scale. The Kelvin scale must be used because zero on the **Kelvin scale** corresponds to a complete stoppage of molecular motion.

Kelvin scale is a scale of temperature with absolute zero as zero, and the triple point of water as exactly 273.16 degrees.

In mathematical terms, the direct relationship of Charles' Law can be represented by the following equation:

VT = k (11.5.1) (11.5.1) VT = k

As seen in the Boyle's Law, k is constant only for a given gas sample. The table shown below provides with the temperature and volume data for a particular amount of gas at a constant pressure. The third column is the constant for this particular data set and is always equal to the volume divided by the Kelvin temperature.

Table 5.1: The Temperature-Volume Data

Temperature (K)	Volume (mL)	$\frac{V}{T} = k \left(\frac{mL}{K}\right)$
50	20	0.40
100	40	0.40
150	60	0.40
200	80	0.40
300	120	0.40
500	200	0.40
1000	400	0.40

Source: https://chem.libretexts.org/Courses/College_of_Marin/Marin%3A_CHEM_114_-_Introductory_Chemistry_(Daubenmire)/11%3A_Gases/11.05%3A_Charles%E2%80%99s_Law%3A_Volume_and_Temperature

When this data is represented graphically, the result is a straight line, indicative of a direct relationship, shown in the figure below.

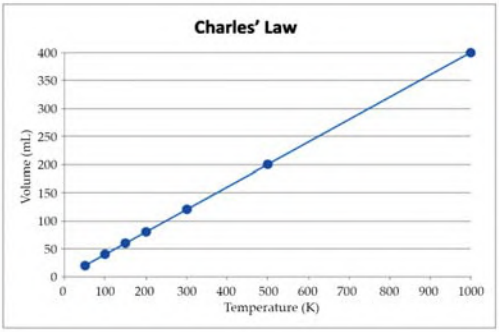

Figure 5.5: The volume of a gas increases as the Kelvin temperature increases.

Source: https://chem.libretexts.org/@api/deki/files/78687/CK12_Screenshot_14-4-2.png?revi *sion=1&size=bestfit&width=509&height=345*

It can be noticed that the path of the line goes in direction of origin which means that at the point of absolute temperature, the volume of gas become zero. Anyhow, when a gas is brought to an extremely cold temperature, condensation takes place and its moles eventually become liquid before it hits the **absolute zero**. The temperature at which certain gas changes its state into liquid is different for different gases.

Absolute zero is the lowest temperature possible. At a temperature of absolute zero there is no motion and no heat. Absolute zero occurs at a temperature of 0 degrees Kelvin, or -273.15 degrees Celsius, or at -460 degrees Fahrenheit.

5.8. VAPOR PRESSURE

Consider an empty container which is half filled with a liquid, in this case a part of liquid evaporates and fills the other remaining volume of the cylinder by vapor. At first, when evaporation of liquid starts, the pressure exerted by the vapors on container's wall increases substantially.

This pressure is called as Vapor Pressure. After some time, the vapor pressure becomes stable and constant and a state of equilibrium is established between the saturated vapor pressure and vapor pressure. As it is known that process of vaporization depends on temperature, it is necessary to mention the temperature readings while providing the vapor pressure of liquid. When heating of a liquid takes place in an open vessel, vaporization of liquid from the surface of liquid takes place.

The temperature at which the vapor pressure of liquid and external pressure becomes equal, the liquid starts vaporizing throughout the liquid bulk and produced vapors expand freely into the surroundings. This stage at which the vaporization happens freely throughout the liquid is called as boiling. Also, the temperature at which both the external pressure and vapor pressure are equal is known as the boiling temperature at that pressure.

At high altitudes atmospheric pressure is low. Therefore, liquids at high altitudes boil at lower temperatures in comparison to that at sea level. Since water boils at low temperature on hills, the pressure cooker is used for cooking food. In hospitals surgical instruments are sterilized in autoclaves in which boiling point of water is increased by increasing the pressure above the atmospheric pressure by using a weight covering the vent. Boiling does not occur when liquid is heated in a closed vessel.

On continuous heating, the vapor pressure increases substantially. At the initial stages a clear separation between the vapor phase and liquid as it is known that liquid has more density as compared to vapor. On further increasing the temperature, more and more molecules convert into vapor phase, rising the density of vapors. At the same time, liquid becomes less dense.

5.8.1. Viscosity

Viscosity is one of the most important characteristic properties of liquids. The definition of viscosity is, “a measure of resistance to flow which arises due to the internal friction between layers of fluid as they slip past one another while liquid flows.” Liquid with high viscosity means that there are strong intermolecular forces in between the molecules that hold them together and prevent the smooth movement of layers over one another. It is interesting to note that when a liquid flow on a surface, then layer of molecules which is in direct contact of surface does not moves (remains stationary). It is also worth mentioning that velocity of upper layer is directly proportional to the distance of layers from the fixed layer that means, with increase in the distance of layers from fixed layer increases, velocity of upper layer increases. Hence, the type of flow in which regular gradation of velocity takes place while passing from one layer to the other is known as **Laminar flow**.

Laminar flow is a flow regime characterized by high momentum diffusion and low momentum convection.

Viscosity is inversely proportional to the flow of liquid. Van der Waals forces and hydrogen bonding are the main reason for causing high viscosity in fluids. The most interesting example is the Glass, which is an extremely viscous liquid.

Glass' viscosity is so high that it mimics some properties of solids also. Anyhow, to experience the property of flow of glass, the thickness of windowpanes of very old buildings can be studied. These windowpanes are found to be thick at bottom and thin at the top. Viscosity of liquids decreases as the temperature rises because at high temperature molecules have high kinetic energy and can overcome the intermolecular forces to slip past one another between the layers.

REVIEW QUESTIONS

1. What does transition of states of matter mean?
2. Explain the kinetic molecular theory in detail.
3. Discuss Charles’ law in brief.
4. Explain the term “viscosity.”
5. Define intermolecular forces.
6. Compare intermolecular forces with thermal interactions.
7. Describe measurable properties of gas.
8. What are the differences in the properties of solid, liquid, and gas?
9. What do you understand by viscous pressure?
10. Define thermal energy.

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CHAPTER

6

CHEMICAL BONDING

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- The concept of chemical bonding
- History of chemical bonding
- Major kinds of chemical bonding
- Lewis symbols and their use

KEYWORDS

- Chemical Bonding
- Polar Covalent Bonds
- Ionic Bonding
- The Octet Rule
- Metallic Bonding
- Valency
- Lewis Dot Diagram
- Theory of Quantum Mechanics
- Coulomb’s Law
- Valence Electron

6.1. INTRODUCTION

Taking the case of everyday world, the chemical bonding can be defined as any interaction which is responsible for associating the different atoms and creating ions, molecules and crystal along with other stable compounds that are responsible for making up the known substances.

To further understand chemical bonding, it happens when different atoms approach each other and electrons and nuclei interact with each other in such a way that it distributes them in a position where total energy is less than that of any other alternative arrangement possible.

In some stances, where the cumulative energies of a group of atoms are found to be lower as compared to the total energies of single atoms combined together, there are chances that these atoms will bond together. The energy lowering in this case will be the bonding energy of the group of atoms

It was during the early 20th century that give birth to the ideas to establish the nature of chemical bonds. It all happened with the discovery of electron and quantum mechanics that created a medium in which the behavior and characteristics of electron present in atoms can be described.

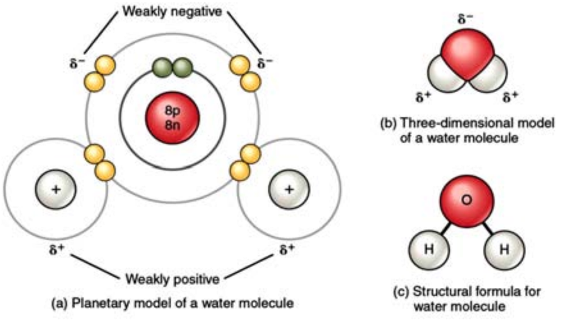
Anyhow, even when the researchers and chemists require quantum mechanics to get a thorough understanding of bond creation, most of their remarkable work and their deep understanding is explained with the help of simple intuitive models. In these models, bonds are treated primarily as of two types: covalent and ionic.

Then nature of bond that will happen between any two atoms can be predicted by looking at their element’s position in the periodic table. Further the type of bond is responsible for the properties of substances so formed up to some extent.

A key concept in a discussion of chemical bonding is that of the molecule. Molecules are the smallest units of compounds that can exist. One feature of molecules that can be predicted with reasonable success is their shape. Molecular shapes are of considerable importance for understanding the reactions that compounds can undergo. For a general understanding, the simple models of bonding prove to be useful and are used as thumb rules in order to rationalize the presence of compounds, but to understand the chemical and physical properties along with the molecular structure, there is a need to justify by appealing to more delicate and sophisticated description of bonding.

Moreover, it is also known that some of the aspects of **molecular structure** are out of scope and cannot be described with the help of simple theories. To understand them in complete detail, it is required to include the quantum mechanics in equation. This inclusion of quantum mechanics heavily rely on latest computers and this numerical approach in chemical bonding imparts crucial information about bonds.

Molecular structure, is the three-dimensional structure or arrangement of atoms in a molecule.



(a) Planetary model of a water molecule

(b) Three-dimensional model of a water molecule

(c) Structural formula for water molecule

Figure 6.1: Polar covalent bonds in a water molecule.

Source: https://courses.lumenlearning.com/ap1/chapter/chemical-bonds/

6.2. THE HISTORY BEHIND THE BONDING

In discussing the historical origin of chemical bonding, it is very difficult to point out a specific origin of this notion. Since the very definition of chemical bonding is based upon the steady modifications of ideas. Further, in order to define a number of such ideas there are several considerable moments worth noting in case of chemical bonding, and a popular publication in early 18th century provides one such moment.

Sir Isaac Newton, in his 1704 publication *OPTICKS*, mentioned a force in this that points towards a modern idea of the chemical bond. In Query 31 of the book, Newton describes "'forces' – other than those of magnetism and gravity – that allow 'particles' to interact."

In year 1718, French chemist Étienne François Geoffroy while translating Opticks in French language developed an Affinity Table. This table presented fascinating first look at the probable chances of some interactions, Geoffroy came across with a relative affinity that different substances have for other substances, and this describes the strength of interaction between these substances.

Chemical bond is a lasting attraction between atoms, ions or molecules that enables the formation of chemical compounds.

While Geoffroy and Newton's work preceded the modern understanding of compounds and elements, their work has given insight into the type of **chemical bonding**. Anyhow, it was more than 100 years before the idea of the combining power of different elements was understood in a further modern way.

In a research report in the journal Philosophical Transactions entitled "On a new series of organic bodies containing metals" (Frankland, 1852), Edward Frankland explains the "combining power of elements," a concept now known as "valency" in chemistry. Frankland summarized his thoughts by proposing what he described as a 'law':

"A tendency or law prevails (here), and that, no matter what the characters of the uniting atoms may be, the combining power of the attracting element, if I may be allowed the term, is always satisfied by the same number of these atoms."

As per the work done by Frankland, it is suggested that any element can only combine with a certain limited number of atoms of different elements as described by the concept of bonding. But the other researches performed by two other scientists provided important contemporary research on the concept of bonding.

During the 1916, Gilbert N. Lewis, an American scientist, published a very famous paper on the concept of bonding namely "The atom and the molecule" (Lewis, 1916). In this popular paper, Lewis describes a member of important concepts about chemical bonding, that are still in practice these days as working models of electron placement at atomic level.

The most important and significant work of Lewis was a theory developed by him about the bonding based on the number of outer shells, or valence electrons in an atom. As per Lewis, a chemical bond is formed when two atoms share a pair of electrons, further, renamed by Irving Langmuir as "Covalent Bond." The "Lewis dot Diagram" given by Lewis uses a pair of dots to show each shared pair of electrons that made up a covalent bond.

The idea of 'octets' i.e. groups of eight was also given by Lewis. It says that a filled valence shell is important to understand the way atoms bond together as well as the **electronic configuration** of molecules. The idea of octets

Electron configuration is the distribution of electrons of an atom or molecule (or other physical structure) in atomic or molecular orbitals.

is not new as it was also discussed by chemists like John Newlands, who knew its importance but Lewis' explanation was more advanced.

6.2.1. The Modern Chemical Bonding

The work of Lewis was further studied by a young chemist by the name of Linus Pauling. Pauling began to study and consider the ways to interpret it in the context of newly developed area of Quantum mechanics. The development of theory of Quantum mechanics took place in first half of the 20th century, and it revolutionized the understanding of atom and hence that theory of bonding seems incomplete if it is not in synchronization with the Theory of quantum mechanics.

The greatest contribution of Pauling's in the field of chemical bonding is considered to be his book "The Nature of the Chemical Bond" (Pauling, 1939). This work mainly describes the linking of physics of quantum mechanics with the chemical nature of electron interactions that takes place while chemical bonds are created.

The basis of Pauling's work was the assumption that "true ionic bonds and covalent bonds sit at extreme ends of a bonding spectrum, and that most chemical bonds are classified somewhere between those extremes." Pauling further created a sliding scale for types of bonds which is governed by the electronegativity of the atoms that take part in the bond creation.

The hard work of Pauling and his immense contribution to the modern understanding of chemical bonds was felicitated by Nobel Prize in 1954 for "research into the nature of the chemical bond and its application to the elucidation of the structure of complex substances.”

6.3. TYPES OF CHEMICAL BONDING

The formation of chemical bonds take place when electrons are sufficiently close to two or more nuclei. In cases beyond this, there is no easy and simply understood theory in existence that can define why atoms bind together to produce molecules, but also define the 3-D structures of the resulting compounds along with the other properties and energy transfers taking place in the bonds.

Unluckily, there is no theory of this kind in existence that can fulfill these goals in an acceptable and reasonable manner for all the different categories of compounds that are known to us. Moreover, it is also likely to happen that if any theory of such kind comes up in time and being, it will be very complex.

In case when we are face to face with the scientific hurdles of this complexity, by experience, it is been found that more emphasis shall be given on the development of models. A scientific model is approximately similar to any theory which can easily make useful predictions along with its assistance in observing different phenomena.

The major advantage that models have over theories is that whereas a theory can be discredited by a single contradictory case, a model can be useful even if it does not encompass all instances of the phenomena it attempts to explain. We do not even require that a model be a credible representation of reality; all we ask is that be able to explain the behavior of those cases to which it is applicable in terms that are consistent with the model itself. Taking an example of model that is already very famous is the Kinetic Molecular Theory of Gases.

Irrespective of the name, this is actually a model (at least at the beginner's level where students are introduced to it) as this does not emphasize on the explanation of behavior of real gases. Anyways, this model plays an important role in the way we understand the behavior of gases, and acts as a starting milestone for more complex and elaborated theories.

The huge and extraordinary variety of the ways in which chemical bonding takes place and atoms combines is no secret, and hence a number of useful bonding models are developed in this regard. Many of the models are useful only for a specific class of compounds, or apply to only a restricted range of phenomena.

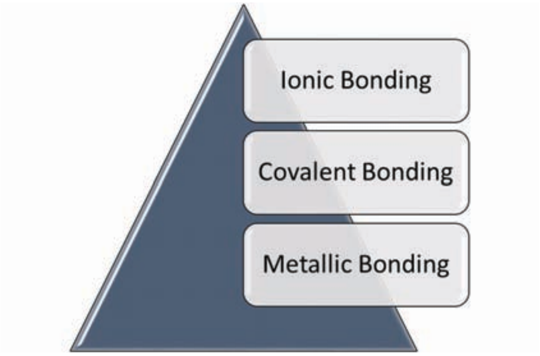


Figure 6.2: Types of chemical bonding.

6.3.1. Ionic Bonding

The atoms or molecules that are electrically charged are called ions. Negatively charged atoms are called anions and positively charged atoms are called cations. Ions are formed when atoms loss or gain electrons. As the electrons carry a negative charge, and when an atom loses one or more electron, it converts to positively charged atom, and when an atom gains one or more electron, it converts to a negatively charged atom.

Hence, **ionic bonding** can be seen as the attraction between positively charged and negatively charged ions. Lattices or ionic networks are formed with the oppositely charged ions attract each other. As explained in electrostatics, "opposite charges attract and like charges repel."

Ionic bonding is the complete transfer of valence electron(s) between atoms and is a type of chemical bond that generates two oppositely charged ions.

In cases where many atoms are attracted towards each other; ordered, large and crystal lattices are formed in which every ion is surrounded by ions of opposite charge. Generally, in cases where metals are reacted with non-metals, electron transfer from the metals to the non-metals take place. The non-metals form negatively charges ions and metals form positively charges ions.

Ionic bonds are formed when metals and nonmetals react together chemically. As per the traditional definition, on one hand, "a metal is comparatively stable if it loses electrons in order to form a complete valence shell and becomes positively charged," and on the other hand, "a non-metal becomes stable by gaining electrons to complete its valence shell and become negatively charged." In the reaction between nonmetals and metals, the electron is lost by metals and it gets transferred to the non-metals, which in turn shows a gain of electron. Similarly, in the same manner, formation of ions takes place, that instantaneously attracts one another and an ionic bond is formed.

6.3.2. Covalent Bonding

Ionic bond formation in which complete transfer of electrons takes place from one atom to another can only take place in very few sets of elements. Covalent Bonding, in which no valence electron is lost completely by either atom, is a very common phenomenon. In a covalent bond a region of space between two nuclei is occupied by electrons and is said to be shared by them.

The origin of this model is marked back to the theory given by Gilbert N. Lewis in 1916, which still remains the most extensively used model in field of chemical bonding. The essential elements in this model can be understood with the help of simplest possible molecule, which is the hydrogen molecule. This hydrogen molecule H_2^{2+} consists of one electron and two nuclei (that will include only two protons, and at it is known, their electrostatic charge will repel each other irrespective of the distance between them).

Further, if we try to create a more simple molecule than H_2^{2+}, such molecule will not exist and it is known that something more than two nuclei is needed for bonding to occur.

An electron is also present in the hydrogen molecule ion H_2^+ as a third particle. The properties of this electron will be dependent on its position with respect to the two nuclei. There can be two scenarios, either electron is between the nuclei or it is off to one side. Considering the first case when the electron is between the nuclei, it will gradually attract both protons towards itself, and thus towards each other.

For the cases where intermolecular repulsion is less than the cumulative energy of molecules, the molecule will reach a stable state because of the 'net bonding effect.' Contrary to this statement, is the electron is present on the one side, both the nuclei will get attracted to that, but due to the inverse square nature of coulomb's law, the nuclei present closer to the electron will be attracted with much more strong force. As a result, **electrostatic repulsion** will be assisted by electrons and both the nuclei will be pushed apart.

Electrostatic repulsion is the result of interaction between the electrical double layers surrounding particles or droplet.

From the above discussion it can be understood that electron is a very important part of chemical bonding, but the position of electron plays an utmost important role. The desirable location for an electron is between the nuclei. Coulomb's Law can be used to evaluate the forces experienced by the two nuclei for the different locations they have been placed.

This helps us in defining two different regions of space around the nuclei. One of the regions is 'binding region' which tells about the locations where the electron applies a net binding force on the new nuclei, on the outer periphery, the region is 'antibonding region' where the electron works against the binding force.

Bond energy can be defined as the amount of energy needed in order to break a gaseous iron pair. Formation process of ionic compounds release a huge of heat and hence, is an exothermic process (extreme) in nature

Further, as per the definition, “the strength of the electrostatic attraction between ions with opposite charges is directly proportional to the magnitude of the charges on the ions and inversely proportional to the internuclear distance”.

It can be noted from the above relation that total energy of the system is perfectly distributed among the attractive interactions between ions with opposite charges and the repulsive interactions between electrons on adjacent ions.

6.3.3. Metallic Bonding

Metals possess a number of qualities that are unique in nature such as a low ionization energy, ability to conduct electricity and a low electronegativity. This results in the fact that metals give away electrons easily and hence are cations. Metallic bonds are a type of covalent bonds as sharing of electrons takes place in this metallic bond.

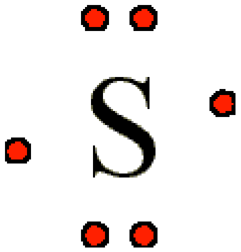
The easiest model of metallic bond is the “sea of electron” model that shows the atoms sitting in a huge sea of valence electrons that are delocalized over all the atoms. As there is no particular bond present in between the individual atoms, metallic bonds are more flexible in nature.

The atoms can freely move around in the sea of electrons and it will keep them together. Some of the metals are soft and have low melting points while some metals are hard and possess very high melting points. This hardness and temperature values depends roughly on the number of valence electrons that form the sea.

6.4. LEWIS SYMBOLS

In the starting of the 20th century, the famous American chemist Gilbert N. Lewis (1875–1946) gave us a system of symbols that is used for prediction of number of bonds that are created in the compounds by most of the elements. This system is called as Lewis electron dot symbols, sometimes also called as Lewis dot symbols. In the Lewis dot symbol, chemical symbols for an element are surrounded by dots that tells about the valence electrons.

To understand the nomenclature of an element's Lewis dot symbol, dots are placed to represent the valence electrons, one at a time, around the elements chemical symbol. A maximum of four dots can be placed below, above, to the right or to the left of the symbol irrespective of the order, till the moment elements with four or less than four valence electrons have no more than one dot in every position).



To place the next dots, the same procedure is followed again, and are distributed one at a time, and are paired with one of the first four dots. As an example, consider the atomic sulfur and its electron configuration is [Ne]3S2 3P4, which shows that the valence electron is six, and this can be depicted as shown below in Lewis symbol.

The number of valence electron and number of dots in Lewis Dot Symbol are same, which is equal to the last digit of the that particular element's group number in the periodic table.

Lewis dot symbol consists of the chemical symbol for an element surrounded by dots that represent its valence electrons.

Unpaired dots were used by Lewis to predict the bonds amount that an element will make while production of a compound. Taking the example of Nitrogen's symbol, with the help of **Lewis Dot symbol**, it can be explained that is why nitrogen tends to make compounds in which it shares the unpaired electrons to form three bonds even when it carries three unpaired valence electrons. Taking other examples like Boron also readily forms compounds with three bonds while having three unpaired valence electrons as depicted in Lewis Dot symbol. Further taking in account the carbon atom, it tends to share all the unpaired valence electron by forming compounds that has four bonds as four unpaired valence electrons are shown in carbon atom in Lewis Dot symbol.

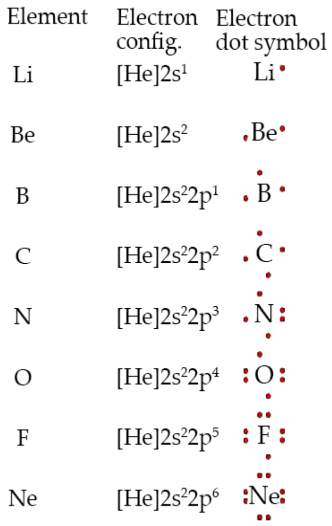


Figure 6.3: Lewis Dot Symbols for the Elements in Period 2.

6.4.1. The Octet Rule

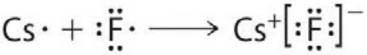
The biggest contribution that Lewis had was to understand the fact that atoms tend to gain, lose and share electrons in order to approach a total of 8 valence electrons which is called as an octet. This octet rule is used to explain the **stoichiometry** of many compounds that are made by using elements in the s and p blocks of the periodic table.

Stoichiometry is a section of chemistry that involves using relationships between reactants and/or products in a chemical reaction to determine desired quantitative data.

Further with the help of Quantum mechanics, we can say that the number 8 corresponds to three np valence orbitals and one ns orbital that in total can have eight electrons. It was remarkable that Lewis's work marked about a decade before the nuclear model of an Atom was proposed by Rutherford.

Some of the general exceptions of the octet rule are helium. Electronic configuration of helium has 1s2 electron configuration and due to this configuration, it gives helium a full n = 1 shell, and other example is hydrogen, which is ready to share or gain its one electron in order to reach the electron configuration similar to helium.

It is also interesting to know that ions in ionic compounds can also be represented by using Lewis Dot symbols. The reaction among the fluorine and cesium to get the CsF, an ionic compound can be written as:



$$Cs\cdot + :\overset{\cdot\cdot}{\underset{\cdot\cdot}{F}}\cdot \longrightarrow Cs^{+}[:\overset{\cdot\cdot}{\underset{\cdot\cdot}{F}}:]^{-}$$

It can be noted that no dots can be seen on Cs^+, reason being the loss of single valence electron of cesium to fluorine. Cs^+ ion is produced after the transfer of the mentioned electron takes place, carrying the same valence electron configuration as Xe and also similar to F^- ion. F^- electrons has a total of eight valence electrons or it can be said that it completes an octet and Ne electron configuration.

The explanation given above is in line with the statement that "among the main group elements, ions in simple binary ionic compounds generally have the electron configurations of the nearest noble gas." The charge that each ion carries is mentioned in the product, and its electrons and anions are enclosed in brackets. With this notation, it can be seen that ions are associated electrostatically and no electron sharing is taking place among two elements.

REVIEW QUESTIONS

1. Describe in brief the formation of a chemical bond.
2. Discuss the role of Étienne François Geoffroy and Linus Pauling in Chemical Bonding.
3. Write a short note on ‘History of Chemical Bonding.’
4. What is the difference between Ionic bond and Covalent Bond?
5. What is a metallic bond?
6. Discuss Lewis symbols in detail.
7. Write a short note on the Octet Rule.
8. What is the application of chemical bonding?
9. Which kind of chemical bonding is the strongest and why?
10. Explain the polar covalent bonds of water molecules.

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CHAPTER

7

ELECTROCHEMISTRY

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- Electrochemistry and its fundamentals
- The technology of electrochemical microsystem
- The definition of electrochemical cell
- The process of electrolysis and its applications

KEYWORDS

- Bipolar Electrochemistry
- Electrochemical Microsystem Technology
- Electrochemical Cell
- Electrolysis
- Non-Metals
- Electrolysis of Water
- Faradays Law of Electrolysis
- Molten NaCl
- Oxidation-Reduction (Redox) Reaction
- Gibbs Energy

7.1. INTRODUCTION

The study of chemical processes due to which electrons' movement take place is called Electrochemistry. In general terms, this movement of electrons is known as electricity. Electricity is produced when electron from one element moves towards the other element. The reaction in which electricity generation takes place is called **oxidation-reduction** (redox) reaction. In a redox reaction, a change in oxidation state of one or more elements takes place.

In case when an electron is lost by an element, its oxidation state increases making the element oxidized. In case when an electron is gained by an element, its oxidation state decreases, making the element reduced. Let's consider an example of redox reaction.

$H_2 + F_2 \rightarrow 2HF$

Can be rewritten as follows:

- Oxidation reaction

$H_2 \rightarrow 2H^+ + 2e^-$

- Reduction reaction

$F_2 + 2e^- \rightarrow 2F^-$

- Overall reaction

$H_2 + F_2 \rightarrow 2H^+ + 2F^-$

As shown in the respective reactions above, the process of oxidation is the loss of electrons, while the process of reduction can be seen as a gain in electrons. The elements that are being oxidized are known as reductants or reducing agents, and on the other hand, the elements that are being reduced are called oxidant or oxidizing agents. In the example mentioned above, F_2 is being reduced (and is the oxidizing agent) and H_2 is being oxidized (and is the reducing agent).

Electrochemistry is seen as a true multidisciplinary science that has numerous applications in number of fields within the chemical, physical and biological sciences.

Some of the key points that will be discussed in this chapter are the areas that include storage and conversion in specific fuel cells and Lithium ion batteries, electro synthesis that includes both the

electrodeposition of homogeneous and organic synthesis along with nanostructured surfaces; corrosion, electroanalytical chemistry in the traditional sense of analyte detection along with information on probing mechanistic about the oxidation and reduction reactions of electroactive species at the nanoscale. At last, the application of electrochemistry in the biological sciences is discussed in brief.

Electrodeposition is a well-known method to produce in situ metallic coatings by the action of an electric current on a conductive material immersed in a solution containing a salt of the metal to be deposited.

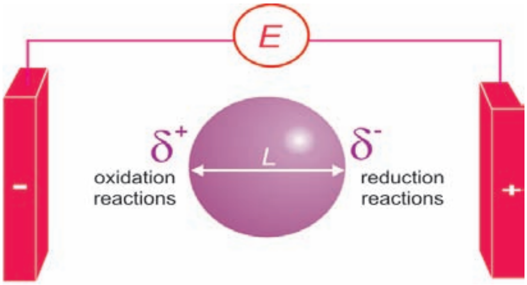

Figure 7.1: Bipolar electrochemistry.

Source: https://commons.wikimedia.org/wiki/File:Bipolar_electrochemistry.jpg

7.2. ELECTROCHEMICAL MICROSYSTEM TECHNOLOGY

Electrochemistry and the principles of electrochemistry includes the basic fundamentals that can refurbish a number of things present in the physical world and are also important for the actions of human beings. It should also be taken into consideration that technologies like electrochemical technology (based upon electrochemistry) is a crucial part of many advanced manufacturing processes and products particularly in the fields of micro-technology which is revolutionizing roughly every aspect of day to day lives.

Electrochemistry is widely accepted for industrial applications especially in the micro manufacturing processes as it helps in achieving desired shape of articles and is easy to implement. It has established a multibillion-dollar market with applications in fields like entertainment, automotive, information, medical, telecom and a lot of other technologies.

Numerous specialized technological and scientific fields like sensors, micro and neurobiology, microelectronics, material sciences along with medicine inspire the scientists and researchers to improve, develop and apply principles of electrochemistry for latest micro-techniques that will have both vertical and lateral resolutions.

EMM or Established electrochemical micromachining techniques require more delicate and fine approaches in order to fulfill the exponential increasing demands of miniaturization and to meet the customized requirements of modern-day applications. Therefore, it is required to know the insights of electrochemical reactions taking place at the very base, i.e., at the microscopic level. These reactions are majorly responsible for the functioning of different microsystems, in order to fulfill the need of different technologies and processes.

Micro electrochemistry acts as an interdisciplinary bridge between micro electrochemistry and science as it is one of the fastest emerging branches of electrochemistry. The most emerging and promising topic of Electrochemical microsystem or EMST have the extended information that generally focus on the applications based on technology.

The main areas of interest are the miniaturization of a single part along with the complete system and on other hand electrochemistry includes the entire scope starting from the reactions to the processes and then to product and ends at the final product. EMST is the interdisciplinary scope and includes the areas like electrochemical engineering, micro engineering, **chemical analysis**, electrochemistry, material science, and applications in medicine and biology.

Chemical analysis is the study of the chemical composition and structure of substances.

Also, it is a challenging task to bring together all the areas and to implement them in getting novel solutions for various applications in nanoscopic and in microscopic field that bring us toward the ideal improvement in the basic EMST.

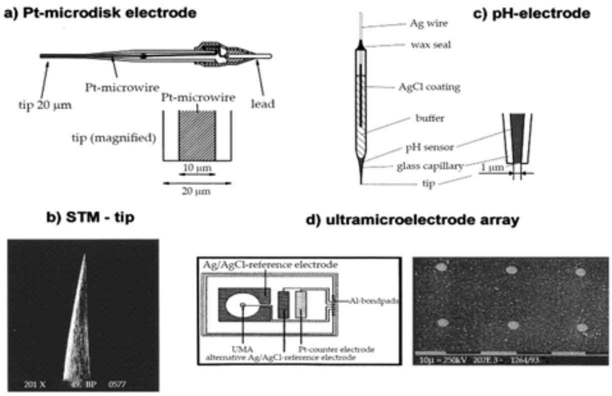

Figure 7.2: Electrochemical microsystem technology.

Source: https://www.sciencedirect.com/science/article/pii/S0013468699000651

7.3. THE FUNDAMENTALS OF ELECTROCHEMISTRY

Electrochemistry is the field that is focused in the chemical phenomena that are linked with the separation of charges mostly in the liquid state for example solutions. The charges separate during a reaction and it is generally associated with the transfer of charge that occurs in solutions that are of different chemical categories in a homogeneous manner, while on electrode surfaces in a heterogeneous manner.

Hence, the electrochemistry has a plethora of applications among different segments are extremely wide, which is discussed in later sections.

So as to confirm the electroneutrality, simultaneous transfer of half reaction takes place in two or more charges in reverse directions reduction (gain of electrons or decrease in oxidation state) and oxidation (loss of electrons or increase in oxidation state).

Electric circuit is a path in which electrons from a voltage or current source flow.

On the surface of electrode, the reduction and oxidation half reactions are different in open space, generally taking place at different electrodes dipped in solution in separate cells or in a single cell compartment. These electrons are linked to one another through conductors placed in both the solutions and external environment. In the solution, conduction takes place through ionic transport and in external environment, it happens through electric wires. This setup is placed in order to convey the charge properly and complete the **electrical circuit**.

The electrical energy released in the experiment can be harnessed through fuel cells and batteries only when the cumulative Gibbs energy change happening at both the ends is found to be negative. In case, the Gibbs energy is positive, the electrical energy from external sources is supplied in order to overcome the difference in the positive Gibbs energy and gratify the electrode reactions to happen and let the electrolysis take place in order to convert chemical substances.

Hence, if it is permissible within the cell configurations, the final product can be separated which is obtained by the reaction of two electrodes, for example, the reactions occur in the industrial electrolyte.

7.4. ELECTROLYSIS AND ELECTROCHEMICAL CELL

Electrochemical cells are the devices that can generate electrical energy with the chemical reactions or the ones that can ease the chemical reactions by introducing the electrical energy in the chemical reactions. One of the best examples is the standard 1.5-volt cell that is for the use of consumers. This cell is also known as Galvanic Cell in which the battery is consists of two or more than two cells that are connected in parallel pattern or in a single pattern.

In these reactions, the transfer of electrical energy into the chemical energy take place, where the electrical energy passes through the chemicals that have ions which are in the molten state or are present in the solution that results in the reduction or in addition that liberates or deposits chemical ions at the electrodes.

This type of electrochemical cell works by the change of chemical energy in the electrical energy. In this reaction, there are two sections that contain one electrode each that are merged in the electrolyte.

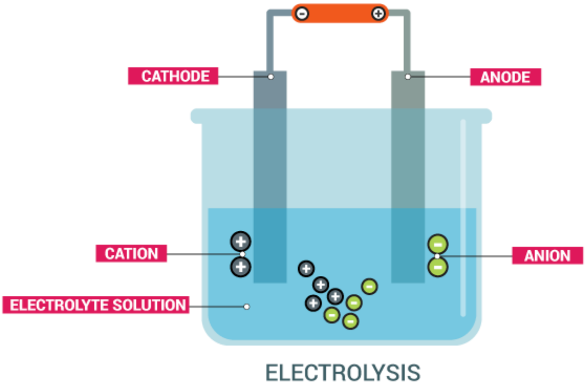

Figure 7.3: Electrolysis.

Source: https://www.toppr.com/guides/chemistry/electrochemistry/electrolytic-cells-and-electrolysis/

7.4.1. Faradays Law of Electrolysis

- There are two Faraday's law of electrolysis. The First law is, "the amount of chemical reaction which occurs at an electrode during electrolysis by a current is proportional to the quantity of electricity passed through the electrolytic solution or melt." The Second law is, "the number of different substances liberated by the same quantity of electricity passing through the electrolytic solution is proportional to their chemical equivalent weights."

In mathematical terms, the Faraday's laws can be stated as:

Q (coulomb) = I (ampere) × t (second)

The value of one Faraday unit is equal to 96,487 C mol^{-1} (generally taken as 96 500 C mol^{-1} for calculations).

7.4.2. The Galvanic Cell

The cell that is responsible for the conversion of chemical energy into electrical energy that culminates out of spontaneous redox reactions is called an electrochemical cell which is also called as voltaic or galvanic cell. The main role is played by Gibbs energy of spontaneous redox reaction that initiates the electrical work done by the galvanic cell.

The components of **galvanic cell** are two half-cells and a salt bridge. A metal electrode is dipped in an electrode in each of the half-cells. These two half cells are connected to each other with the help of a switch along with a voltmeter in an external fashion with the help of metallic conducting wires. In case, the electrolyte is same for both the electrodes, there is no need of salt bridge in the reaction.

Galvanic cell is a type of electrochemical cell. It is used to supply electric current by making the transfer of electrons through a redox reaction.

There are several times when the electrolyte and electrode are interface each other, in most of these cases, electrode is in direct contact with electrolyte and hence, atoms that are in metal electrode generates ions in that solution of electrolyte, leaving behind the electrons in the electrode itself. Due to this reaction chain, the electrode (metal) behaves like a negatively charged electrode. In parallel, during the same time, the metal ions of the electrolyte solution tend to get collected on the electrode (metal), making the electrode a positively charged electrode.

The difference that generates between the electrolyte and the electrode is known as Electrode Potential. In case of an equilibrium condition, observation of charge separation depends on the tendency of the two reactions opposing each other. The electrode in this can be negatively charged or positively charged.

Anode is the electrode where the process of oxidation takes place. As compared to the solution, charge carried by anode is negative. Further, on the other hand, cathode is the electrode where the process of reduction takes place. Cathode is positively charged with respect to the solution.

The difference between the negative potential and positive potential is known as Cell Potential. Cell Potential of galvanic cell is also called the electromotive force of the galvanic cell. In other words, the highest potential difference possible in between the anode and cathode of the galvanic cell is the electromotive force or cell potential.

There are a few rules that are required to be followed when to represent an electrochemical cell which are mentioned as below:

- The electrode on the right side is always cathode and the electrode on the left side is always anode.
- In the nomenclature, name of metals is written first, followed by the metal ions that are in the electrolyte. A vertical line must be mentioned to separate these.

- After the name, the molar concentration is mentioned, which is written in brackets, just next to the names. e.g., A Daniel cell can be represented as

$Zn \mid Zn^{2+} \parallel Cu^{2+} \mid Cu$

The cell notation for the same will be

$Zn \mid Zn^{2+}\ (1M) \parallel Cu^{2+}\ (1M) \mid Cu$

7.5. ELECTROLYSIS OF SODIUM CHLORIDE

Among the various methods of electrolysis of Sodium Chloride, the two most common methods of electrolysis that are in practice are electrolysis of molten sodium chloride and aqueous sodium chloride, which give different end results. As we have discussed earlier, electrolysis is the process in which direct electric current is passed through an ionic substance, which is either in the molten or dissolved state to be used as a suitable solvent.

The output of this is a chemical reaction-taking place at electrodes and the separation of materials takes place. Most two common techniques implemented for the electrolysis are: using molten sodium chloride as electrolyte and using aqueous sodium chloride as electrolyte. The end product of both the reactions is different although the base material is the same. Let's discuss both the methods to comprehend the different processes.

Electrolysis is a technique that uses a direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction.

7.5.1. Electrolysis of Molten NaCl

To melt the NaCl, it is heated to the temperature of 801°C. Then the two electrodes are dipped into this molten NaCl and electric current is passed through this molten salt. A chemical reaction hence takes place as mentioned below:

- At first, Sodium ions moves toward the cathode. At cathode, electrons enter the melt and they are reduced to sodium metal:

$$Na^{+} + e^{-} \rightarrow Na$$

- Second step is the migration of Chloride ions toward the anode. Chloride ions drop their electrons at the anode and form chlorine gas by oxidizing:

$$Cl^{-} \rightarrow \frac{1}{2}Cl_2 + e^{-}$$

- The whole reactions are the breakdown of sodium chloride into its base elements, as shown below:

$$2NaCl \rightarrow 2Na(\mathrm{s}) + \mathrm{Cl}_2(\mathrm{g})$$

Considering the second case, where the aqueous solution of Sodium Chloride is used in place of molten NaCl. In this case the water is the added component into the equation. As it is known that water can be both reduced and oxidized, it competes against the ions of Na^+ and Cl^- dissolved in the solution. In this reaction, hydrogen is produced in place of sodium.

In a commercial electrolysis cell used for the production of chlorine gas and metallic sodium from the melt of NaCl, the following steps shall be followed: Liquid Sodium can be collected form the top as it floats over the cathode and is drained in the tanks for storage.

Above anode, chlorine gas is bubbled out from the melt of NaCl. As mentioned in the reaction below, Sodium ions migrates towards the cathode, where electrons are introduced to the melt and are reduced to the sodium metal.

[latex] {Na} ^ {+} + {e} ^ {-} \ right arrow Na [/latex]

Chloride ions migrate the other way, toward the anode. They give up their electrons to the anode and are oxidized to chlorine gas:

Chlorine gas moves to the opposite direction, towards anode, it loses its electron at the anode and get oxidized to chlorine gas:

[latex] {Cl} ^ {-} \ right arrow \ frac {1} {2} {Cl} {2} + {e} ^ {-} [/latex]

The whole reaction is the breakup of Sodium Chloride into its base elements:

[latex] 2NaCl \right arrow 2Na (s) + {Cl} _ {2} (g) [/latex]

As a result of electrolyzing the aqueous solution of NaCl, the result is the chloride gas and hydrogen gas. At the left end, i.e. anode (A), chlorine is obtained by oxidation of chloride (Cl^-). The membrane (ion selective membrane) permits the free flow of counter ions Na^+ across the electrolyte while restricting the free flow of anions like chloride and hydroxide (OH^-). At the cathode (C), reduction of water into hydrogen gas and hydroxides takes place. This process can be summarized into the process of electrolysis of aqueous solution of NaCl in order to manufacture the industrially viable compounds like chlorine gas and sodium hydroxide (NaOH).

7.6. ELECTROLYSIS OF WATER

When an electric current is passed through the water, due to electrolysis, it decomposes into hydrogen and oxygen. As a result of created electric potential, positive ions are produced that also includes the inherent ions of hydrogen H_3O^+ which move in the direction of negative electrode or cathode and negative ions that includes inherent hydroxide ions OH^- that proceed towards the positive electrode or anode.

When the required potential difference in present, the process of electrolysis initiates with the oxygen gas that is produced at anode and hydrogen gas which is produced at the **cathode**. For the electrolysis of water, generally a dilute or moderately concentrated salt solution is used in order to minimize the power loss that drives the current through the solution. The presence of salt is not a necessary requirement for the electrolysis of water.

Cathode is the electrode from which a conventional current leaves a polarized electrical device.

Usually during the electrolysis, the water near the electrodes has a different pH, reason being the production or consumption of ions. In case if the compartment of electrode is divided by the suitable porous membrane, then the concentration of OH^- in the catholyte and the concentration of H_3O^+ in the anolyte (which in turn will increase the respective conductivities) are supposedly mark an increase as compared to the case when the free mixing of electrodes is allowed because most of these ions will react and neutralize one another.

This will result in an expected small difference in the pH levels of the solution at the cathode or catholyte and at anode or anolyte, that in turn mark a minimal variation in the overall potential difference required (1.229 V). Rise in the acid concentration next to the anode because of the H_3O^+ produced that will rise the electrode potential (for example: pH 4 E = +0.992 V) and rise in the alkaline content near to the cathode due to the OH^- produced will be the reason in making of electrode potential more negative (for example: pH 10 E = –0.592 V). If the cathode reaction is forcibly run at pH 0.0 and anode reaction is forcibly run at pH 14, then the electrode potentials are 0 V and +0.401 V, respectively.

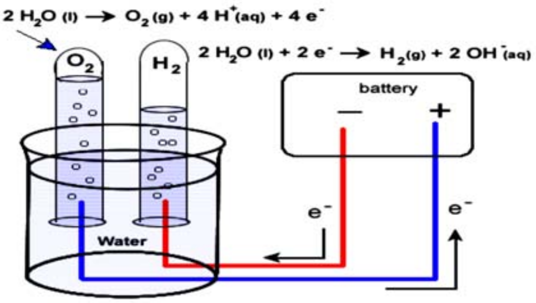

Figure 7.4: Electrolysis of water.

Source: https://chem.libretexts.org/Under_Construction/Purgatory/Core_Construction/Chemistry_30/Electrochemistry/3.3_Electrolysis_of_Water

A considerable amount of time is consumed for the solubilities to reduce from their initial stage of super **saturation state** to their desired equilibrium state after the process of electrolysis is over.

Saturation state is the point where a phase change begins or ends.

While the procedure is described in theoretical terms, the electric current passing through shall tell about the quantities of oxygen and hydrogen formed in the reaction, many factors make sure that some low quantities of gas are actually received, like:

- In some cases, products are re-converted into H_2O with the help of catalysts at the electrodes, especially in the cases where no membrane division is there between the compartments of electrolytes.
- Anode is oxidized by some of the oxygen.
- While performing measurements, some gas may escape.
- Some of the end products and electrons can be consumed in the side reactions, which cannot be controlled.
- This may also happen that some of the gas particles are held up in form of nano-bubbles for a long time.
- Also, some of the hydrogen atoms can be absorbed by the cathode, especially if the cathode used is palladium.

The description given above does not tell all the aspects and over simplifies the whole process. For consideration, the actual electric potential needed at any point of time in the electrolytic cell is evaluated by the local concentration of the products and reactants that include the instantaneous gas partial pressure, local pH of the solution along with the net effective surface area of the electrode due to attached gas bubbles.

The potential differences along the cell are not consistent and there is proof of the formation of some charge zones on a large scale that are kinetically stable. It is also interesting to note that efficiency of electrolysis increases substantially with the rise in the temperature as the hydrogen bonding reduces. The overall energy demand is neutralized as on one hand the heat demand increases due to the endergonic process and on the other hand the electrical demand decreases.

Also, the pressure and current are directly proportional to each other and inversely proportional to the gas and heating effect, as with rise in the pressure over the electrolysis, the more current passes for the same voltage applied and, the heating effect and output gas per coulomb are both decreased. The reason for this behavior is the increase in the solubility of gases and small size of bubbles that reduces the cell resistance and increases the recombination reactions.

Further, reduction in the distance between the electrodes, decreases the resistance of the electrolysis medium, the productivity of the process may degrade as due to the closeness the gas starts to build up between the electrodes.

The transition of pulsed potential from low to high speeds up the rate of reaction (current) and substantially increases the mass transfer rate in the electrolyte and the motion of bubbles from electrode surface. This in turn reduces the electrochemical polarization taking place at the diffusion layer and also rising the efficiency of hydrogen production. The use of magnetic field, with or without the optical enhancements can further increase the rate of change of current density which in turn will increase the efficiency.

Pure water with no impurities acts as an **insulator** and conducts electricity very poorly and this being the reason it is very difficult to electrolyze. In normal cases, anyhow, some salts are already present in the ground water or tap water that are sufficient for the process of electrolysis to take place at significant rates. Further, these salts and specifically the chloride ions, then undergo the redox reactions at one of the electrodes. The disadvantage of these side reactions is that it produces new solutes and gases, and reduce the efficiency of the electrolysis reactions.

Also, in addition these solutes at electrodes may get in a reaction with one another to produce other materials. These side reactions are complex in nature and this complexity in reaction somewhat increases when the voltage applied to the cell is more than that needed for the above processes and reactions. The probable reactions taking place in the electrode compartment are shown below. These are the standard electrode potentials that are shown, some reactions mentioned may only take place to a very small extent and other reactions out of the ones mentioned below can also occur that are not included.

Insulator is a material that does not conduct electrical current.

7.7. APPLICATIONS OF ELECTROLYSIS

Electrolysis is a very useful and important process for industrial and commercial purposes. The process has a lot of important applications that are successfully implemented in large scale manufacturing processes. Some of the credible applications of electrolysis are mentioned below:

- According to second law of electrolysis, “when the same quantity of electronic current is passed through solutions of salts of two different cells, the amounts of the metals deposited on the cathodes of the two cells are proportional to their equivalent masses of the respective metals.”

- If the amounts of the metals deposited on the cathodes be W_A and W_B respectively, then

$$\frac{W_A}{W_B} = \frac{Equivalent\ Mass\ of\ A}{Equivalent\ Mass\ of\ B}$$

- With the help of statement mentioned above, the equivalent mass of one metal can be evaluated, if the equivalent mass of other metal is known.
- Further, by using the above relation, the equivalent mass of nonmetals, that are evolved at anodes can also be calculated.

7.7.1. Manufacture of Non-Metals

Electrolysis is very successful in obtaining non-metals like fluorine, hydrogen, and chlorine.

Electro-refining of metals:

Electrolysis finds a huge application scope in refining the metals that is basically removing the unwanted substances from the metal. Some metals like silver, copper, gold, tin and aluminum are refined very efficiently with the help of electrolysis.

Manufacture of compounds:

- Compounds like KOH, NaOH, white lead, $KMnO_4$ and $KClO_3$, etc. are majorly manufactured using the process of electrolysis.

Electroplating:

The process of coating an inferior metal with a superior metal by electrolysis is known as electroplating. The aims of electroplating any metal are:

- To make it more stable and attractive in appearance.
- To prevent the inferior metal from corrosion and extend its life.

To electroplate the metal by using electrolysis, the metal to be electroplated is made the cathode and a piece of metal that will go over the inferior metal works as an anode, dipped in an electrolytic bath that contains a solution of salt of anodic metal. When the electric current is passed through the circuit, the metal at anode starts dissolving out and is start to get deposit on the metal piece at the cathode in form of a thin film. The following points must be taken into care for a fine electroplating to happen:

- The article should have a rough surface in order to ensure the permanent deposit of metal on the surface.
- The article surface should not have greasy matter and the oxide layers to ensure the smooth process. It is recommended to clean the surface with detergents or chromic acid.
- It should be made sure that current

density should be same throughout.

- In order to get a smooth and finished coating, the concentration of the electrolyte should be set appropriately.

7.7.2. Extraction of Metals

There are two widely used methods implemented for the extraction of metal. These methods are based on the physical form of the ore. In the first process, the ore is brought in contact with a strong acid that gives a salt and solution of such salt undergoes the electrolysis in order to release the pure metal. In the second method. The ore is melted and the process of electrolysis takes place in a furnace.

(i)Extraction of Zinc:

Sulfuric acid is used to treat the zinc ore. Then the electrolysis is performed on the zinc sulfate solution which is obtained after treating the zinc ore with Sulfuric acid. In the electrolysis tank, the anode is made of lead and the cathode is made of aluminum. The zinc metal is deposited on cathode and current density is kept at 1000 A/m^2 to obtain the said results. In this electrolysis, the total energy consumption is around 3000 to 5000 KWH per tonne.

(ii)Extraction of Aluminum:

The aluminum ores are cryolite and bauxite. These are treated chemically and reduced to aluminum oxide and then dissolved in fused cryolite and electrolyzed in a furnace. In this process, the aluminum is procured from the cathode and it settles at the bottom. In order to keep the electrolyte in a fused state, **furnace** temperature is set at about 1000°C.

Furnace is a device used for high-**temperature** heating.

7.7.3. Refining of Metals

The main benefits of extraction of a metal by process of electrolysis are that the purity of product that we get is 98–99%. Further refining is also possible by electrolysis. The anode is made of the extracted metal. Pure metal gets deposited at the cathode. The electrolyte is made of the metal solution, e.g., for copper, it is copper sulfate and for nickel, it is nickel chloride.

REVIEW QUESTIONS

1. Describe the oxidation reaction and reduction reaction in brief.
2. Write a short note on electrochemical microsystem technology.
3. What are the basic fundamentals of electrochemistry?
4. Discuss the Faraday’s laws of electrolysis.
5. Write a short note on the galvanic cell.
6. Explain the electrolysis of sodium chloride in detail.
7. Describe the electrolysis of water briefly.
8. What are the major applications of electrolysis?
9. Write a short note on electroplating.
10. Define the term electro refining.

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CHAPTER

8

THE UNITS OF MEASUREMENTS

LEARNING OBJECTIVES:

In this chapter, you will learn about:

- The units of measurement
- History of SI system
- Different units of measurement
- International System of Units and the Metric System
- The significance of measurement

KEYWORDS

- Avogadro’s Number
- Candela
- Fluorescent Light Sources
- International System of Unit
- Luminous Intensity
- Measurements
- Metric System
- Mole
- SI System
- Units of Measurement

8.1. INTRODUCTION

Measurement is the foundation of trade, science, technology and quantitative research in many disciplines. Every field of science involves taking measurements, understanding them, and communicating them to others. This explanation includes a quantitative description, comparison, and measurement of certain physical quantities. For this we need to speak the same basic language. Therefore, we need to fix some standard unit of the quantity to measure or compare a physical quantity and explain it to others. Whether you are a chemist, a physicist, a biologist, an engineer, or even a medical doctor, you need a consistent way of communicating size, mass, shape, temperature, time, amount, energy, power, and speed.

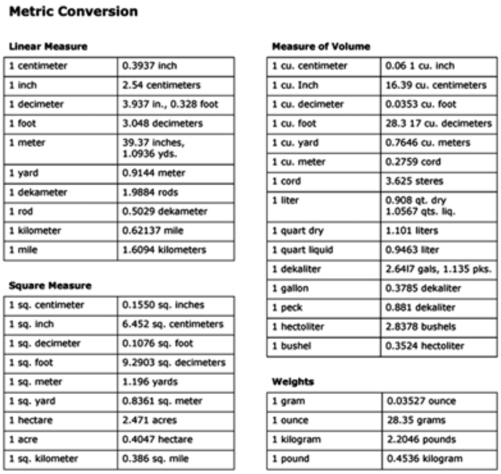
The weight of an apple is heavier than a strawberry. But how many times? Radha is taller than Priya, but how tall? To answer such questions, we need to fix some unit. Suppose mass is the unit, then we can conclude that weight of an apple is 7–8 times to that of a strawberry. Similarly, if we use length as a unit, we can easily determine that Radha is 3 times unit taller to that of Priya. Thus, the physical quantities are described in terms of a unit of that quantity.

Another example could be the LCD screen of the computer which is made up of liquid crystals. The formulation of the liquid crystals is developed by the chemist who needs to transfer the meaningful information to the engineer so that he knows how to manufacture it. The engineer further communicates the information to the other engineers, chemists, physicist, technicians etc. who design the circuit boards, display screens and other electronic interfaces of the computer system. In the whole complicated process, if all the involved people don’t speak the same language, the final outcome will never be there, or in other words, the enterprise will never get off the ground.

Any quantity which can be measured is called a physical quantity. A certain basic, arbitrarily chosen, internationally accepted standard of reference used to measure the physical quantity is called a unit. Measurements most commonly use the International System of Units (abbreviated SI, from the French Système international d’unités) as a comparison framework.

It is the standard modern form of the **metric system** and is used in science, industry and medicine. Another system of units called as 'Imperial Units' which was earlier used officially across British Empire. It includes units such as gallons, feet, miles and pounds. These units are still used for some "everyday" measurements in a few places in the United Kingdom but have been mostly replaced by the metric system in all commercial, scientific and industrial applications.

Metric system is an internationally recognised decimalised system of measurement.



Metric Conversion

Linear Measure

1 centimeter	0.3937 inch
1 inch	2.54 centimeters
1 decimeter	3.937 in., 0.328 foot
1 foot	3.048 decimeters
1 meter	39.37 inches, 1.0936 yds.
1 yard	0.9144 meter
1 dekameter	1.9884 rods
1 rod	0.5029 dekameter
1 kilometer	0.62137 mile
1 mile	1.6094 kilometers

Square Measure

1 sq. centimeter	0.1550 sq. inches
1 sq. inch	6.452 sq. centimeters
1 sq. decimeter	0.1076 sq. foot
1 sq. foot	9.2903 sq. decimeters
1 sq. meter	1.196 yards
1 sq. yard	0.8361 sq. meter
1 hectare	2.471 acres
1 acre	0.4047 hectare
1 sq. kilometer	0.386 sq. mile

Measure of Volume

1 cu. centimeter	0.06 1 cu. inch
1 cu. Inch	16.39 cu. centimeters
1 cu. decimeter	0.0353 cu. foot
1 cu. foot	28.3 17 cu. decimeters
1 cu. yard	0.7646 cu. meters
1 cu. meter	0.2759 cord
1 cord	3.625 steres
1 liter	0.908 qt. dry 1.0567 qts. liq.
1 quart dry	1.101 liters
1 quart liquid	0.9463 liter
1 dekaliter	2.6417 gals, 1.135 pks.
1 gallon	0.3785 dekaliter
1 peck	0.881 dekaliter
1 hectoliter	2.8378 bushels
1 bushel	0.3524 hectoliter

Weights

1 gram	0.03527 ounce
1 ounce	28.35 grams
1 kilogram	2.2046 pounds
1 pound	0.4536 kilogram

Figure 8.1: Unit conversions.

Source: https://quincy.instructure.com/courses/6241/quizzes/14723

8.2. SCIENTIFIC UNITS THE SI AND METRIC UNITS

The scientific units of the SI System, the metric system and the CGS system (centimeter–gram–second system of units) have been given emphasis by Mr. Causey. Mr. Causey also shares the major prefixes and their meanings as mentioned below.

8.2.1. Units of the SI System

There are seven base units in the SI system:

- the kilogram (kg), for mass;
- the second (s), for time;
- the kelvin (K), for temperature;
- the ampere (A), for electric current;
- the mole (mol), for the amount of substance;
- the candela (cd), for luminous intensity;
- the meter (m), for distance.

The use of the SI system provides all scientists and engineers with a common language of measurement.

8.3. HISTORY OF THE SI SYSTEM

The SI units of measurement have an interesting history, but they have been modified and refined over the years for more clarity and simplicity.

- The meter (m), or meter, was originally defined as 1/10,000,000 of the distance from the Earth's equator to the North Pole measured on the circumference through Paris. But advances in the laser measurement techniques of measuring speed of light in a vacuum had made it possible to establish an accurate and easily reproducible standard so meter was thus defined in the SI system as equal to the distance traveled by light in a vacuum over a time interval of 1/299,792,458 of a second.

- The kilogram (kg) was originally intended to be exactly equal to the mass of a liter (i.e., of one thousandth of a cubic meter). It is currently defined as the mass of a solid cylinder of platinum-iridium kilogram sample maintained by the Bureau International des Poids et Mesures in Sevres, France.
- The second (s) which is the base unit of time in SI system was originally defined as 1⁄86,400 of a day – this factor derived from the division of the day first into 24 hours, then to 60 minutes and finally to 60 seconds each. Although the historical definition of seconds was based on this division of Earth's rotation cycle of 23 hours, 56 minutes, and 4.1 seconds, the current definition of seconds in the International System of Units (SI) is much reliable. 1 second is defined to be exactly "the duration of 9,192,631,770 periods of the **radiation** corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom."
- Ampere or amp (symbol: A) is the unit of electrical current. It is a measure of the amount of electric charge passing a point in an electric circuit per unit time. 6.241×10 18 electrons, or one

Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium.

coulomb, per second constitutes one ampere. Here electric charge is used as the base unit, with the unit of charge defined by measuring the force between two charged metal plates.

- The Kelvin (K) is the unit of the thermodynamic temperature scale. One kelvin is formally defined as 1/273.16 of the thermodynamic temperature of the triple point of pure water (exactly 0.01°C, or 32.018°F). The Kelvin scale differs from the more familiar Celsius or centigrade (0°C) temperature scale. This scale starts at 0 K. There is no such thing as a below-zero Kelvin figure. A temperature of 0 K represents absolute zero, the absence of all heat. However, the size of the kelvin "degree" is the same as the size of the Celsius "degree."
- The mole (mol) is the base unit of the amount of substance. It is a number that relates molecular or atomic mass to a constant number of particles. It is defined as the amount of substance that contains as many elementary entities as there are atoms in 0.012 kg of carbon-12. As per the new definition, the mole is defined as the amount of a chemical substance that contains exactly 6.02214076×10 23 (Avogadro constant) constitutive particles, e.g., atoms, molecules, ions or electrons.
- The candela (cd) is the standard unit of luminous intensity. Originally, luminous intensity was measured in

terms of units called candles. This expression arose from the fact that one candle represented approximately the amount of visible radiation emitted by a candle flame when candles were the most common source of illumination. This was an inexact specification because burning candles vary in brilliance. Now, with the prevalence of incandescent and fluorescent light sources, the candela is defined as the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540×10^{12} Hertz and that has a radiant intensity in that direction of 1/683 watts per steradian.

8.4. THE UNITS OF MEASUREMENTS

Measurements provide the macroscopic information that is the basis of most of the hypotheses, theories, and laws. Chemists study and describe the behavior of matter and energy in three different domains of chemistry-macroscopic, microscopic, and symbolic. Macroscopic domain includes every day and laboratory chemistry, where we observe and measure physical and chemical properties, or changes such as density, solubility, and **flammability**.

Flammability is the ability of a chemical to burn or ignite, causing fire or combustion.

Aspects of the microscopic domains are visible through a microscope, such as a magnified image of graphite or bacteria or viruses. Symbolic domain contains the specialized language used to represent components of the macroscopic and microscopic domains. Chemical symbols, chemical formulas, and chemical equations are part of the symbolic domain, as are graphs and drawings. We can also consider calculations as part of the symbolic domain. In all the three domains, units of measurement serve as the basis of standard information.

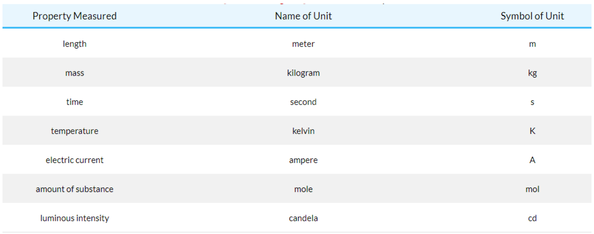
Every measurement provides three kinds of information: the size or magnitude of the measurement (a number); a standard of comparison for the measurement (a unit); and an indication of the uncertainty of the measurement. While the number and unit are explicitly represented when a quantity is written, an uncertainty represents the random and systemic of the measurement procedure; it is more implicitly represented and indicates a confidence level in the measurement.

The number in the measurement can be represented in different ways, including decimal form and scientific notation. For example, the maximum takeoff weight of a Boeing 777-200ER airliner is 298,000 kilograms, which can also be written as 2.98×10^5 kg. The mass of the average mosquito is about 0.0000025 kilograms, which can be written as 2.5×10^{-6} kg.

Units, such as liters, pounds, seconds and centimeters, are standards of comparison for measurements for length, weight, time and volume. When we buy a 2-liter bottle of a soft drink, we expect that the volume of the drink was measured, so it is two times larger than the volume that everyone agrees to be 1 liter. The meat used to prepare a 0.25-pound hamburger is measured so it weighs one-fourth as much as 1 pound. Thus, first for convenience and then for necessity, standards of measurement evolved so that communities would have certain common benchmarks.

Without units, a number can be meaningless, confusing, or possibly life threatening. Suppose a patient is prescribed phenobarbital by a doctor to control his seizures and a dosage of "100" is stated without specifying units. This will be confusing to the medical professional giving the dose. Also, the consequences can be fatal: 100 mg given three times per day can be effective as an anticonvulsant, but a single dose of 100 g is more than 10 times the lethal amount.

Table 8.1: Base Units of the SI System



Property Measured	Name of Unit	Symbol of Unit
length	meter	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K
electric current	ampere	A
amount of substance	mole	mol
luminous intensity	candela	cd

Source: https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_A_Molecular_Approach_(Tro)/01%3A_Matter%2C_Measurement%2C_and_Problem_Solving/1.6%3A_The_Units_of_Measurement

Sometimes, a given unit is not an appropriate size to easily express a quantity. In that case, we use units that are fractions or multiples of a base unit. E.g., Ice cream is sold in quarts (a familiar, non-SI base unit), pints (0.5 quart), or gallons (4 quarts). We also use numerical prefixes to indicate decimal fractions or multiples of various units in order to make a unit more conveniently sized for a specific quantity. These prefixes are the fractions or multiples of units in the SI system which are always powers of 10. For example, a length of 1000 meters is also called a kilometer because the prefix kilo means "one thousand," which in **scientific notation** is 10^3 (1 kilometer = 1000 m = 10^3 m).

Scientific notation is a way of expressing numbers that are too big or too small to be conveniently written in decimal form.

8.5. INTERNATIONAL SYSTEM OF UNITS AND THE METRIC SYSTEM

The International System of Units, abbreviated SI from the French Système International D'unités, is the modern metric system of measurement units used in science. SI is rapidly becoming the dominant measurement system used in international commerce. In 1960 an international system of units was agreed upon specifying a particular choice of metric units called as SI units for use in scientific measurements.

The SI system has seven base units from which all other units are derived. These SI base units are based on physical standards. With the advancements in science, new base units are being added and the definition too is being modified over the years. Each SI base unit except the kilogram is described by stable properties of the universe.

There are seven base units, which are listed in Table 8.1. Primarily five of the mentioned seven units are most commonly used. They are: the kilogram for mass, the meter for length, the second for time, and the kelvin for temperature and the mole for amount. Besides Kelvin, the degree Celsius (^{o}C) is also commonly used for temperature. The numerical relationship between Kelvin and degree Celsius is as follows:

K = °C + 273

Seven dimensionally independent, base units are defined in terms of the defining constants which are assumed irreducible by convention. In other words, the size of each base unit is defined by international convention. For example, kilogram is the base unit of measurement and is defined by the quantity of mass of a special platinum alloy cylinder, carefully stored in the suburbs of Paris. Other base units have also been defined in the similar manner.

The sizes of the base units are not always convenient for all measurements. Sometimes, it is necessary to deal with measurements that are very small (as in the size of an atom) or very large (as in numbers of atoms). In these cases, it is often necessary to convert between units of metric measurement or provides a series of prefixes that can be attached to the units.

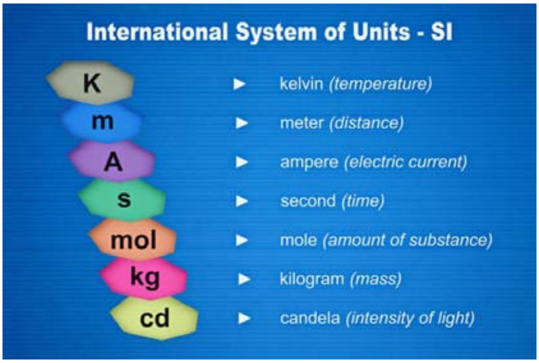


Figure 8.2: International System of Units.

Source: https://www.thoughtco.com/international-system-of-measurement-si-2699435

For example, a meter is a rather large unit for describing the width of something as narrow as human hair. Instead of reporting the diameter of hair as 0.00012 m or even 1.2×10^{-4} m, SI creates units, by attaching prefixes that are larger or smaller by powers of 10, known as the metric system.

SI unit is the modern form of the metric system and is the most widely used system of measurement.

Common prefixes and their multiplicative factors are listed in Table 8.2 “Prefixes Used with SI Units.”

It is important to note that the kilogram is the only **SI unit** with a prefix as part of its name and symbol, kilo- meaning 1,000 ×, and a unit of mass, the gram.) With this exception, any SI prefix may be used with any SI unit, including the degree Celsius and its symbol °C.

Example: 10^{-6} kg = 1mg (one milligram),
but not 10^{-6} kg = 1μkg (one micro kilogram)

Some prefixes create a multiple of the original unit:

1 kilogram = 1,000 grams (or 1 kg = 1,000 g), and

1 Megameter =1,000,000 meters (or 1 Mm = 1,000,000 m).

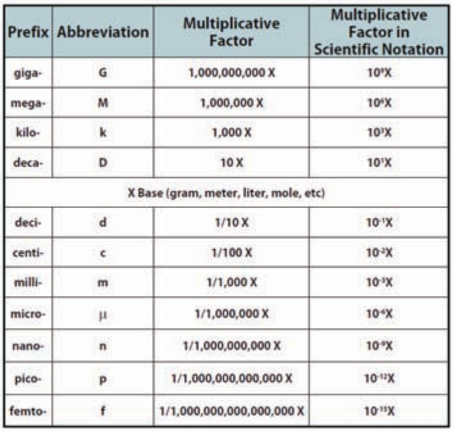
Other prefixes create a fraction of the original unit.

Thus, 1 centimeter =1/100 of a meter,

1 millimeter = 1/1,000 of a meter,

1 microgram = 1/1,000,000 of a gram, and so forth.

Table 8.2: Prefixes Used with SI Units



Prefix	Abbreviation	Multiplicative Factor	Multiplicative Factor in Scientific Notation
giga-	G	1,000,000,000 X	10^9X
mega-	M	1,000,000 X	10^6X
kilo-	k	1,000 X	10^3X
deca-	D	10 X	10^1X
X Base (gram, meter, liter, mole, etc)			
deci-	d	1/10 X	10^{-1}X
centi-	c	1/100 X	10^{-2}X
milli-	m	1/1,000 X	10^{-3}X
micro-	µ	1/1,000,000 X	10^{-6}X
nano-	n	1/1,000,000,000 X	10^{-9}X
pico-	p	1/1,000,000,000,000 X	10^{-12}X
femto-	f	1/1,000,000,000,000,000 X	10^{-15}X

Source: http://www.wou.edu/chemistry/courses/online-chemistry-textbooks/foundations-general-organic-biological-chemistry/chapter-1-measurements-chemistry/

8.5.1. Mass

The mass of an object is a fundamental measure of the amount of matter in the object. The basic unit of mass in the International System of Units is the kilogram. A kilogram is equal to 1000 grams or in a reversal of reference and defined units, a gram is defined as one thousandth of the SI base unit, the kilogram or 1×10^{-3} kg.

Thus, a gram is a relatively small amount of mass and so larger masses are often expressed in kilograms. In case of measuring very tiny amounts of matter, we often use milligrams which are equal to 0.001 gram. Besides these numerous larger, smaller, and intermediate mass units are also available for appropriate measurement. Until the end of the 18th century, the kilogram was originally defined as the mass of a liter of water. That was an inconvenient quantity to precisely replicate. To solve the problem, scientists created a cylindrical hunk of mass called the international prototype kilogram (IPK) from platinum and platinum-iridium alloy. Since then, the kilogram is equal to the mass of this international prototype, which is carefully stored in Paris, France.

Mass and weight are not the same thing. In common usage, the mass of an object is often referred to as its weight, though these are in fact different concepts and quantities.

- In scientific contexts, the mass of an object is a measure of the amount of matter in it while weight is the measurement of the pull of **gravity** on an object. The weight of an object is determined by the force that gravitation exerts upon the object. In other words, an object with a mass of 1.0-kilogram weighs approximately 9.81 Newtons on the surface of the Earth, which is its mass, multiplied by the gravitational field strength.
- The mass (amount of matter) of an object remains the same regardless of where the object is placed. It doesn't change when an object's location changes. For example, moving a brick to the moon does not cause any matter in it to disappear or be removed. Weight, on the other hand does change with location. Since the force of gravity is not the same at every point on the Earth's surface, the weight of an object is not constant.

Gravity is a natural phenomenon by which all things with mass or energy—including planets, stars, galaxies, and even light—are brought toward (or gravitate toward) one another.

For example, a man who weighs 180 pounds on Earth would weigh only 45 pounds if he were in a stationary position, 4,000 miles above the Earth's surface. This the same man would weigh only 30 pounds on the moon because the moon's gravity is only one-sixth that of Earth. The mass of this man, however, would be the same in each situation.

- Mass is measured by using a balance comparing a known amount of matter to an unknown amount of matter. Weight is measured on a scale.

Because mass and weight are separate quantities, they have different units of measure. In the SI system of units, the kilogram is the basic unit of mass, and the newton is the basic unit of force.

For scientific experiments, it is important to measure the mass of a substance rather than the weight to retain consistency in the results regardless of where you are performing the experiment.

8.5.2. Length

Length is a measure of distance. The SI unit of length is the meter. The centimeter and the kilometer, derived from the meter, are also commonly used units. The meter was originally defined in 1793 as one ten-millionth of the distance from the equator to the North Pole – as a result the Earth's circumference is approximately 40,000 km today. In 1889, it was redefined in terms of a bar of platinum-iridium alloy stored under conditions specified by the International Bureau of Standards. In 1960, the definition of the meter was again replaced in terms of a certain number of wavelengths of a krypton-86 radiation. Finally, in 1983, the current definition was adopted which says the meter is the length of the path traveled by light in a vacuum during a time interval of a second or precisely 1/299,792,458 of a second.

8.5.3. Temperature

When used in a scientific context, the words heat and temperature do NOT mean the same thing. Heat and temperature are related to each other but are different concepts. Temperature is a measure of the average kinetic energy of the particles that make up a material. As the temperature increases, thermal energy of the material also increases. Thermal energy is the energy that comes from heat.

This heat is generated by the movement of tiny particles within an object. The faster these particles move; the more heat is generated. Thus, it is the sum of the kinetic and **potential energy** in the particles that make up a material. Heat is the thermal energy transferred from a hotter system to a cooler system that are in contact. Objects do not "contain" heat; rather they contain thermal energy.

Potential energy is the energy held by an object because of its position relative to other objects, stresses within itself, its electric charge, or other factors.

Scientists define heat as thermal energy transferred between two systems at different temperatures that come in contact. The thermal energy will flow in that direction until the two objects are at the same temperature. When the two systems in contact are at the same temperature, we say they are in thermal equilibrium. Temperature is not energy, but a measure of it. Heat is energy.

A thermometer is a device that measures temperature. The name comprises of “thermo” which means heat and “meter” which means to measure. The temperature of a substance is related to the average kinetic energy of the particles of that substance. When a substance is heated, some of the absorbed energy is stored within the particles, while some of the energy increases the motion of the particles.

This is stated as an increase in the temperature of the substance. At a given temperature, the particles of any substance have the same average kinetic energy. In other words, the temperature of a substance is directly proportional to the average kinetic energy it contains. When a substance is continually cooled, the average kinetic energy of its particles decreases. Eventually when the temperature is zero, the particles stop moving completely. At this point, the average kinetic energy must also be zero.

Absolute zero is the temperature at which the motion of particles theoretically ceases. This was the base of the calculations of a third temperature scale designed by Lord Kelvin in which zero degrees corresponds with zero kinetic energy, that is, the point where molecules cease to move. The Kelvin temperature of a substance is directly proportional to the average kinetic energy of the particles of the substance.

Lord Kelvin stated that there is no upper limit of how hot things can get, but there is a limit as to how cold things can get. The temperature scale based on the idea of absolute zero is known as Kelvin temperature scale.

Temperatures measured on the Kelvin scale are reported simply as K, not °K.

Celsius temperature scale, also known as centigrade scale, is the scale based on 0° for the **freezing point** of water and 100° for the boiling point of water. It is sometimes called the centigrade scale because of the 100-degree interval between the defined points.

Freezing point is the temperature at which a liquid becomes a solid at normal atmospheric pressure.

The degree Celsius besides expressing specific temperatures along its scale (e.g., "The temperature outside is 23°C") is also suitable for expressing temperature intervals: differences between temperatures or their uncertainties, e.g., ("The temperature outside is hotter by 4°C compared to the previous day").

Most of us are familiar with temperatures that are below the freezing point of water. Even at the air temperature of -5 ° C, the molecules of air are still moving (i.e. 0° C is not absolute zero). Substances like oxygen gas and nitrogen gas have already melted and boiled to vapor at temperatures below –150°C.

The Fahrenheit temperature scale is also defined by the freezing point and boiling points of water. This scale based on 32° for the freezing point of water and 212° for the boiling point of water, the interval between the two being divided into 180 equal parts. The conversion formula for a temperature that is expressed on the Celsius (°C) scale to its Fahrenheit (°F) representation is:

$$[°C] = ([°F] - 32) \times 5/9 \qquad \text{or} \qquad [°F] = [°C] \times 9/5 + 32$$

The Kelvin is the same size as the Celsius degree, so measurements are easily converted from one to the other. Absolute zero on a Kelvin scale is equivalent to −273.15°C. Therefore, the freezing point of water is 0°C = 273.15 K; the boiling point of water is 100°C = 373.15 K. The Kelvin and Celsius scales are related as follows:

K = °C + 273.15

In the case of the Kelvin scale, the degree sign is not used. Temperatures are expressed simply as 450 K, and are always positive.

8.5.4. Time

A unit of time is used as a standard way of measuring or expressing duration. The SI unit for time is the second. The second was originally defined as a tiny fraction of the time required for the Earth to orbit the Sun or as 1⁄86400 of a day– this factor derived from the division of the day first into 24 hours, then to 60 minutes and finally to 60 seconds each. It has since been redefined several times.

The current definition of seconds in the International System of Units (SI) is “the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

8.5.5. Amount

The SI unit of amount is the mole. A mole of a substance is defined as the mass of substance containing the same number of fundamental units as there is atoms in exactly 6.022 × 10^{23} things. The number 6.022 ×1023, called Avogadro’s number after the 19th-century chemist Amedeo Avogadro. Avogadro's number or constant is the number of elementary particles such as molecules, atoms, compounds, etc. per mole of a substance.

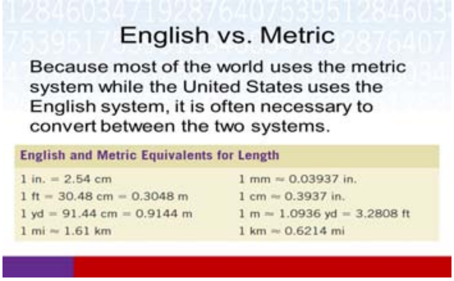
It is the number we use in chemistry to represent macroscopic amounts of atoms and molecules and is expressed as NA. Thus, if we have 6.022×10^{23} Oxygen atoms, we say we have 1 mol of Oxygen atoms. If we have 2 mol of Na atoms, we have $2 \times (6.022 \times 10^{23})$ Na atoms, or 1.2044×10^{24} Na atoms. Similarly, if we have 0.5 mol of benzene (C_6H_6) molecules, we have $0.5 \times (6.022 \times 10^{23})$ C_6H_6 molecules, or 3.011×10^{23} C_6H_6 molecules.

8.6. METRIC SYSTEM VS. "ENGLISH SYSTEM"

The metric system is an internationally agreed decimal system of measurement. The official system of measurement in almost every country in the world, it is based upon the metric system. In the metric system, each basic type of measurement (length, weight, capacity) has one basic unit of measure (meter, gram, liter).

Root word is a word or word part that can form the basis of new words through the addition of prefixes and suffixes.

It typically uses one **root word** for any basic dimension and all other metric units that are based on the use of that root word. As for length, the root word is meter. All the metric units use the word meter with the metric prefix in the next table like kilometer, centimeter, millimeter, decimeter, etc.



English vs. Metric

Because most of the world uses the metric system while the United States uses the English system, it is often necessary to convert between the two systems.

English and Metric Equivalents for Length	
1 in. = 2.54 cm	1 mm ≈ 0.03937 in.
1 ft = 30.48 cm = 0.3048 m	1 cm ≈ 0.3937 in.
1 yd = 91.44 cm = 0.9144 m	1 m ≈ 1.0936 yd ≈ 3.2808 ft
1 mi ≈ 1.61 km	1 km ≈ 0.6214 mi

Figure 8.3: English system of measurement.

Source: https://slideplayer.com/slide/6154051/

US has not adopted the metric system as its “official” system of measurement although awfully accepted for use in the United States in 1866. In US English System of measurement people secured measurements using body parts and familiar objects.

For example, human foot was used to measure shorter ground distances and longer distances were measured by paces, where one mile being 1,000 paces. Cups, pails (formerly called gallons) and baskets were used to measure capacities. Fathoms were used to measure depth in water and furlongs to measure distance in horse racing.

Obviously, such system calls for discrepancies as the measurements were obtained by different individuals. Then the standards were set to ensure equality in measurements.

The way to relate one English unit to another is by definition. Length is the most common measurement. As a result, it has not only the largest number of words to describe it, but it also has the largest number of symbols to represent it in formulas. The English language also uses distance, long, width, height, radius, displacement, offset, and other words for length, sometimes in specialized applications.

Following are some differences between the “English System” and the Metric System, or SI:

- The simplicity of the metric system arises from the fact that there is only one unit of measurement (or base unit) for each type of quantity measured (length, mass, etc.). The prefixes attached to the metric units carry the same meaning for all the bases. Only one root word for each basic dimension is used, such as “meter” for length, “gram” for mass. Metric prefixes are used before the root word to indicate the magnitude of the measurement, such as kilogram or microgram.

So, length, for example, is always measured in meters in the metric system; regardless of whether you are measuring the length of your finger or the length of the Nile River. This is much simpler than the English system of measurement, in which we have to remember inches, feet, miles, yard and many more units of measurement.

- In metric system, to simplify things, very large and very small objects are expressed as multiples of ten of the base unit. The units are arranged in powers of ten, according to their metric prefixes. Metric prefixes can be used with any base unit.

For example, a kilometer is 1,000 meters, a kilogram is 1,000 grams, and a kiloliter is 1,000 liters. While the English System uses any traditional definition with any number. One foot equals twelve inches, or one yard equals three feet. Even worse, the English System even uses FRACTIONS of units, such as 3/8 inch or mixed units, such as pounds and ounces or feet and inches.

- The Metric system distinguishes between MASS and WEIGHT – mass being a measure of the amount of material contained in an object and weights the gravitational force on that object. So, to measure the amount of material, it uses the idea of mass rather than weight. While the English System uses the POUND as a unit of weight, even though it is also a unit of force.
- The metric system is the preferred system of scientific units and the majority of the countries in the world employ the metric system. US too is now SLOWLY beginning to convert to the Metric System. They buy soda by liters, machine car parts in millimeters and measure medicine in milligrams. The food labels also show Metric units.

Gravitational force is a **force** that attracts any two objects with mass.

8.7. THE IMPORTANCE OF MEASUREMENT

The metric system is a simple system of measuring with three main units, meter, kilogram and second. With those three simple measurements we can measure nearly everything in the world. But what if we want to talk about really big or really small things? Here comes the importance of metric prefixes, like “kilo” (a thousand) and “milli” (one thousandth) and so on.

So, something that is 1,000 meters is a “kilometer,” a very short time of one thousandth of a second is a “millisecond.” Measuring a human’s mass in grams would not make much sense because the measurement would be such a large number. Instead, scientists use kilograms because it is easier to write and say that a human has a mass of 90 kilograms than a mass of 90,000 grams.

New scientific instruments and additional prefixes have been added over the years, such as femto- (10^{-15}) and exa- (10^{18}) so as to allow scientists to measure even smaller and larger amounts.

When taking scientific measurements, it is important to be both accurate and precise. Accuracy is how close a measured value is to the actual (true) value. Precision is how close the measured values are to each other or the ability to take the same measurement and get the same result repeatedly.

Accuracy is important because bad equipment, poor data processing or human error can lead to inaccurate results that are not very close to the truth. Unfortunately, measurement is never 100% precise or accurate, so the true value measure of something is never exactly known. This uncertainty of measurement is the doubt that exists about the result of any measurement.

It is a result of Error. Error is the difference between the measured value and the ‘true value’ of the thing being measured. Manually measuring something always involves uncertainty because it is based on judgment. If two people use a ruler to measure how tall a plant is, it may look like 20 cm to one person and 18 cm to the other.

To increase the accuracy of a measurement, and therefore reduce error, an object should always be measured more than once. It is wise to make any measurement at least three times repeatedly. If repeated measurements give different answers, it is best to take many readings and take an average. An average gives you an estimate of the 'true' value.

For example, when measuring an object, you determine its length to be 10.50 cm; when you measure it again, you get a measurement of 10.70 cm. If you average these measurements, you get 10.60 cm. The length of the object is most likely closer to 10.60 cm than it is to either 10.50 cm or 10.70 cm.

IMPORTANCE of Measurement

- It is the basic need in any research work in science.
  - Including labs and activities of science courses.
- Exact, careful and precise work of measurement leads to the discovery of very important laws.

Figure 8.4: Importance of measurement.

Source: https://www.slideshare.net/pglaynn/measurements-53892589

Error can be of two types: random error and systematic error.

- Random – where repeating the measurement gives a randomly different result. If so, the more measurements you make, and then average, the better estimate you generally can expect to get. Random errors are not controllable, and their occurrence is random and due to chance.

- Systematic – where the same influence affects the result for each of the repeated measurements. These errors have a known cause for occurrence and are thus controllable. They can result from many things such as instrument error, method error, or human error. With precautions, they can usually be identified, reduced or even eliminated.

REVIEW QUESTIONS

1. What is a unit? Name the system of units accepted internationally.
2. Explain the SI system of units.
3. In short, explain the history of SI system and how the different units of measurement have evolved overtime.
4. Define mass. What is the difference between mass and weight?
5. Define the SI unit of length.
6. How is temperature different from heat?
7. Explain the three scales of temperature and the relationship between them.
8. What is the SI unit of time? Define it.
9. Explain the difference between Metric system and English system of measurement.
10. Explain accuracy and precision. What are the two types of errors?

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INDEX

General Chemistry

Chemistry has been a subject that has helped in the evolution of humans in a manner that very few of the other subjects have. Chemistry finds its applications across verticals such as food, medical, manufacturing, and other crucial aspects on which the humans depend for existence.

Chemistry as a subject is taught to students so that they know about the basics of chemistry in case they encounter any regular problem of reference to the chemicals, say in case of salts in a medicine.

At higher levels of the study and teaching of chemistry, other information comes in like the kinds in which chemistry is divided, the reactions and the product that they give, the chemistry of physical occurrences of chemicals and compounds and other such areas of concern.

This book brings the focus of the readers to the topics that cover almost all aspects related to chemistry so that they get a complete idea of chemistry in a short composition. The book introduces the general form of chemistry to them, which might be valuable in explaining all the basics of chemistry to the readers in an appropriate way.

The book explains the readers about the relation that chemistry holds with other sciences. The readers should know the reason behind any subject they want to read and the relevance it holds in the physical world. This will help them have an interest in the subject and feel more connected with it.

The book also discusses the different kinds of chemistry and what each kind deals in. All the elements in chemistry are depicted in a tabular form that is commonly known as the periodic tables. The placing of each element that is found on earth has been done very thoughtfully so as to organize all the elements in several categories and classify them to study about their physical or chemical occurrence.

The book explains the periodic table in detail to the readers so that they are absolutely clear with the basics of the periodic table. It also informs the readers about the development of the periodic table and the history it holds with regard to the manner in which the elements have had been added to the table.

There is a special significance that solutions hold in chemistry. It explains the various states in which the solutions can be found and the concept of equilibrium in the solutions. The readers are informed about the energy that is produced in the formation of a solution.

The book also focuses on the various parameters that decide the solubility of solutions and the bonds that are formed in order to form a solution. It also explains the meaning of ideal and non-ideal solutions and the relevance they hold.

The book further moves to introduce the topics of salts, bases, and acids. The readers are explained about each of them. The book explains the readers about their occurrence, formation, importance, uses, and all other aspects related to them. It also informs them about some of the most commonly used compounds and what they are according to the classification, so that readers get a first-hand experience of the relevance of all three kinds.

The readers are informed about the process of bonding in chemistry. The book informs them about the different kinds of bonds that exist between various elements in a compound and explains them about the formation of all the kinds of bonds. The book also tells them about the significance of each kind of bond.

The book moves further to discuss the process of electrolysis and informs the readers about various ways in which it can be done and can prove beneficial to the chemical evolution. This it tells the readers about the process of extraction of ions and other such processes.

The book then elaborates on the various units of measurement in the subject of chemistry. It focuses on the SI units and the various conventional and traditional units of measurement, their inter-conversion, and their readability and the manner in which they can be interpreted.

Rainer Roldan Fiscal is an Associate Professor in Laguna State Polytechnic University, Philippines and Research Coordinator of the College of Teacher Education. He finished Bachelor of Secondary Education major in General Science, Master of Arts in Teaching major in Science and Technology and Doctor of Philosophy in Education major in Educational Leadership and Management. He teaches Biological and Physical Science subjects, Professional Education subjects and Methods of Research in the undergraduate and graduate programs. He presented his papers in national and international conferences in the Philippines and abroad. He published his papers in international journals.

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