# UNIT - 1

## SOME BASIC CONCEPTS IN CHEMISTRY

**Learning Objectives:** On learning this unit students will be able to:

- Understand importance Chemistry in the engineering field
- classify matters
- chemical formula of compounds and calculate percentage.

### 1.1 GENERAL INTRODUCTION AND SCOPE OF CHEMISTRY

Chemistry plays very important role in our everyday life. There is no aspect of our life that is not affected by the developments in chemistry. Since beginning of this branch of science it has been in the service of mankind. Chemistry is playing a vital role in the cultural, industrial and economic development of fast developing society. Our daily needs of food, clothing, shelter, potable water, medicines etc. are directly or indirectly connected with chemical compounds, processes and principles. We always owe a debt to chemists for their important contributions for giving us various valuable things in the followings areas:-

1. Life saving things i.e. medicines
2. Synthetic fibers
3. Synthetic detergents
4. Variety of cosmetics
5. Preservatives for our food
6. Fertilizers, pesticides
7. Paper, glass, strength materials
8. Plastics
9. Beautiful colours (paints)
10. Computer chips, LEDs etc.

#### 1.1.1 Chemistry and its branches

The branch of science which deals with systematic study of composition, structure and properties of matter, chemical changes that matter can undergoesat different conditions, and the laws govern these changes.

Though chemistry has several branches, but followingthreeare important branches of chemistry:

a) **Inorganic Chemistry**: The branch of chemistry which deals with the study of elements other than Carbon and their compounds.
b) **Organic Chemistry**: The branch of chemistry which deals with the study of carbon and its compounds.

c) **PhysicalChemistry**: The branch of chemistry which deals with the law of chemistry combinations and rate factor affecting rate of reaction.

## 1.2 MATTER AND CLASSIFICATION OF MATTER

**Matter:**Matter is defined as anything that occupies space and possesses mass.One can feel the matter byour senses. Some examples of matter are air, water, chair, glass etc.
Classification of matter: Based on state and their chemical nature matter can be classified in two ways:

a) **Physical Classification** - based on state of matter
b) **Chemical Classification -** based on chemical nature of matter.

a) **Physical Classification**:
Matter can exist mainlyinthree differentphysical states and plasma state is fourth state of matter.
1. **Solid**: Substances which possess definite shape and definite volume are called solids. Some examples of solid aresugar, wood, pen, pencil, chair etc.
2. **Liquid**: Substances which does not possess definite shape but have definite volume are called liquids. They take the shape of the container (vessel) in which they are placed. Some examples of liquid are milk, water, oil, tea, coffee etc.
3. **Gas**: Substances which possess neither definite shape nor definite volume are called gases.Some examples of gases are Air, hydrogen ($H_2$), nitrogen ($N_2$), oxygen ($O_2$), chlorine ($Cl_2$) etc.
4. **Plasma state**:This state of matter is regarded as fourth state and exists in under special circumstances. For examplematter in the sun and fluorescent tube is in plasma state.

b) **Chemical Classification**: Matter can be divided into two category based on chemical nature of matter.
i) **Pure Substances:**The substances made up of only one typeof matter or have uniformchemical composition or have identical properties throughout.Pure Substances are further classified into elements and compounds.
a) **Element**: The pure substance which is made up of one kind of atoms is called element. Itis also defined as the simplest form of a pure substance which cannot be to a simpler substance. Element cannot be synthesized by the chemical combination of other substances.
Hydrogen (H), oxygen (O), Nitrogen (O), Iron (Fe), Silver (Ag) and Carbon (C) are some examples of elements.
b) **Compound**:A compound is defined as the pure substance which contains two ormore elementscombined together in fixed ratio by mass(or pure substance formed by the chemical combination of two or more elements combined in the

fixed ratio by mass).The constituents of compound can be separated by suitable chemical methods.

Water ($H_2O$),Carbondioxide ($CO_2$), Sodium chloride (NaCl), Methane ($CH_4$), and Vinegar ($CH_3COOH$) are some examples of compounds.

ii) **Mixture**:Mixture is defined as the substance formed by mixing two or more than twoor more substances (elements or compounds) in any ratio by mass.

Heterogeneouscombination of two or more substances, in any ratio by mass, which cannot be represented by single chemical formula, is called mixture.

Examples of mixtureare Air, glass, soil, sand, milk, paints, alloys, sea water, plastics, cement, blood, tap water (amixture of solids and gases dissolved in water), salt solution, and sugar solution etc.

**Note:** Mixtures are of two types:

a) Homogeneous mixture: Mixture containing two or more substances which are uniformly dispersed in each other in single phase. Air, milk, paints, alloys, tap water (a mixture of solids and gases dissolved in water), salt solution, and sugar solution are some homogeneous mixtures.

b) Heterogeneous mixture: Mixture containing two or more substances which are not uniformly dispersed in each other in single phase substance. Soil, sand in water, kerosene and water are some heterogeneous mixtures.

**Table 1.1:Difference between compounds and mixture**

| Compounds | Mixture |
|---|---|
| The constituent are present in fixed ratio by mass | The constituent are present in any ratio by mass (or volume) |
| It is always homogenous | It may or may not be homogenous |
| Its properties are different from the properties of its constituentelements. | Its properties are entirely different from the properties of its constituent substances. |
| Compound is characterized by sharp melting point (boiling point). | It has no sharp melting point (boiling point). |
| A compound is formed as a result of chemical change associated with definite amount of energy change (i.e. heat evolved or absorbed). | A mixture is formed as a result of physical change which involves no or low amount of energy change (i.e. heat evolved or absorbed). |
| The constituents of a compound cannot be separated by simple methods. | The constituents of a compound can be separated by simple methods. |

**1.2.1 Atom**: An atom is smallest indivisible particle of an element which possessesidentical propertiesof that element and may or may not haveindependent existence.For example, the atoms of Helium (He),Neon (Ne), Argon (Ar), and Gold (Au)exist independently.But the atom of Hydrogen,Oxygen,and Nitrogen does not exist independently. These exists as $H_2$ (Hydrogen), $O_2$ (Oxygen), $N_2$ (Nitrogen).

**1.2.2 Molecule**: A molecule is defined as the simplest and smallest particle of a substance which has independent existence. Example: $CH_4$(Methane), $H_2O$(Water), $H_2$(Hydrogen),

$O_2$ (Oxygen), $N_2$ (Nitrogen), Acetic acid ($CH_3COOH$) $H_2SO_4$ (Sulfuric acid) and NaOH (Sodium hydroxide) are few examples of molecules.

**Molecules are of two types**:

a) Homo-atomic molecules are made up of atoms of same element. For example, $H_2$ (Hydrogen), $O_2$ (Oxygen), $N_2$ (Nitrogen), $O_3$ (Ozone), $P_4$ (Phosphorous), $S_8$ (Sulfur).

b) Hetero-atomic molecules are made up of two or more than two kinds of atoms (i.e. two or more atoms of different elements).Example, Acetic acid ($CH_3COOH$) $H_2SO_4$ (Sulfuric acid) and NaOH (Sodium hydroxide) and $KClO_3$(Potassium chlorate) are some examples of hetero-atomic molecules.

Table 1.2: Types of molecules based on number and type of atoms in a molecule

| Molecules | Mono atomic | Di atomic | Tri atomic | Poly atomic |
|---|---|---|---|---|
| Based on number of elements present in them | molecule consisting of only one atom | molecules consisting of two atoms | molecules consisting of three atoms | molecules consisting of more than three atoms |
| **Homo atomic molecules** | He, Ne,Ar,Fe, Al, Auetc. | $H_2$,$O_2$, $N_2$ etc. | $O_3$ (Ozone) | $P_4$, $S_8$, |
| **Hetero atomic molecules** | -- | HCl, CO, KI, NaCl, MgO | $CO_2$, $SO_2$, $NO_2$, $H_2O$, $N_2O$, NaOCl, NaOH | $CH_3COOH$ $KClO_3$, $H_2SO_4$ |

**1.2.3 Ion:** An atom or group of atoms carrying charge is called ion.

Examples: $H^+$(Hydrogen ion), $NH_4^+$(Ammonium ion), $OH^{-1}$(hydroxide), $Cl^{-1}$ (chloride ion), $Cu^{+2}$ (Cupric ion) etc

Types of ions:

a) Ion carrying positive charges is called cation (electro positive) or positively charged ion is called cation.Examples:$H^+$ (Hydrogen ion), $NH_4^+$ (Ammonium ion), $Cu^{+2}$ (Cupric ion) etc.

Cation is formed by the loss of one or more electrons (oxidation) by an atom or group of atoms.

$H \rightarrow H^+ + e^{-1}$ $Cu \rightarrow Cu^{+2} + 2\ e^{-1}$.

(Hydrogen atom) (Hydrogen cation) (Copper atom) (Cupric cation)

b) Ion carrying negative charges is called anion (electro negative)or negatively charged ion is called anion.Examples:$OH^{-1}$ (hydroxide), $Cl^{-1}$ (chloride ion) etc.

Antion is formed by the gain of one or more electrons (reduction) by an atom or group of atoms.

$Cl_2 + 2e^{-1} \rightarrow\ 2\ Cl^{-1}$ $\frac{1}{2}\ O_2 + 2\ e^{-1} \rightarrow O^{-2}$.

(Chlorine) (chloride anion) (Oxygen) (oxide anion)

**1.2.4 Symbol:**In 1814 Berzelius suggested representation of every element using symbol. Chemical symbol is the abbreviation (or shorthandnotation) used to represent scientific name of an element.According to Berzelius, first letter of name of the element in capital is used to represent the element. If two or more elements have names with same letter, then the first letter in capital along with a small letter which is prominent in the name is used to represent the element.

Examples: Boron symbol is B, Beryllium is Be, Hydrogen symbol is H, Helium symbol is He, Carbon is C, Cerium is Ce, Nitrogen is N, Neon is Ne, and Sulfur is S, Selenium is Se.

There are 120 elements known so far in the periodic table, name of some elements are derived from Latin, German and Greeklanguages.

Table 1.3:Names of elements derived from Latin language.

| Latin name | Symbol | English name |
|---|---|---|
| Natrium | Na | Sodium |
| Kalium | K | Potassium |
| Ferrum | Fe | Iron |
| Arum | Au | Gold |

Table 1.4:Some common elements and their symbols and atomic mass (**A***)

| **Sr. No.** | **Name of element** | **Symbol** | **A*** | **Sr. No.** | **Name of element** | **Symbol** | **A*** |
|---|---|---|---|---|---|---|---|
| 1 | Hydrogen | H | 1 | 21 | Scandium | Sc | 45 |
| 2 | Helium | He | 4 | 22 | Titanium | Ti | 48 |
| 3 | Lithium | Li | 6.9 | 23 | Vanadium | V | 51 |
| 4 | Beryllium | Be | 9.1 | 24 | Chromium | Cr | 52 |
| 5 | Boron | B | 10.8 | 25 | Manganese | Mn | 55 |
| 6 | Carbon | C | 12 | 26 | Iron | Fe | 56 |
| 7 | Nitrogen | N | 14 | 27 | Cobalt | Co | 58.9 |
| 8 | Oxygen | O | 16 | 28 | Nickel | Ni | 58.7 |
| 9 | Fluorine | F | 19 | 29 | Copper | Cu | 63.5 |
| 10 | Neon | Ne | 20 | 30 | Zinc | Zn | 65.4 |
| 11 | Sodium | Na | 23 | 31 | Bromine | Br | 80 |
| 12 | Magnesium | Mg | 24 | 32 | Silver | Ag | 108 |
| 13 | Aluminium | Al | 27 | 33 | Cadmium | Cd | 112.4 |
| 14 | Silicon | Si | 28 | 34 | Tin | Sn | 118.7 |
| 15 | Phosphorous | P | 31 | 35 | Iodine | I | 127 |
| 16 | Sulfur | S | 32 | 36 | Barium | Ba | 137 |
| 17 | Chlorine | Cl | 35.5 | 37 | Platinum | Pt | 195 |
| 18 | Argon | Ar | 40 | 38 | Gold | Au | 197 |
| 19 | Potassium | K | 39 | 39 | Mercury | Hg | 200.6 |
| 20 | Calcium | Ca | 40 | 40 | Lead | Pb | 208 |

**Significance of symbol:**

Chemical symbolof an element gives both qualitative and quantitative information:

1. Qualitative information

   Symbol of an element represents name of particular element and distinguish it from rest of elements.

   B is Boron, howeverBe is Beryllium.

   H is Hydrogen and He is Helium.

   C is Carbon and Ce is Cerium.

2 Quantitative information
   Though, symbol represents one atom or one molecule of the element. It signifies one mole element that contains6.023 x $10^{23}$ atoms or molecules of the element.

Table 1.5: Qualitative and Quantitative significance of symbol

| Element | Symbol of | | Quantity<br>1 mol element = 6.023 x $10^{23}$ atoms (or molecules) |
|---|---|---|---|
| | Atom | Molecule | |
| Sodium | Na | Na | One mole Na = 1 mol Na = 6.023 x $10^{23}$ Na atoms |
| Hydrogen | H | $H_2$ | One mole H = 1 mol H = 6.023 x $10^{23}$ H atoms<br>One mole $H_2$ = 1 mol $H_2$ = 6.023 x $10^{23}$ $H_2$ molecules |

**1.2.5 Radical:** An atom or a group of atoms which forms the part of an inorganic compound is called a radical. For example:

NaCl is made up of two parts i) $Na^+$, Sodium cation andii) $Cl^{-1}$, chloride anion

$MgSO_4$contain two parts i) $Mg^{2+}$, Magnesium cation and ii) $SO_4^{2-}$, sulfate anion

Radicals are of two types

Basic radicals: Radicals having positive charge are called basic radicals. They are also known as electropositive radicals. Examples of basic radicals are $Na^+$, $Mg^{2+}$ (refer Table 1.6 A).

Acidic radicals: Radicals having negative charge are called acidic radicals. They are also known as electronegative radicals. Example of acidic radicals are $Cl^-$, $SO_4^{2-}$(refer Table 1.6 B).

Table 1.6A:Basic radicals or electropositive radicals

| Classification based on charge carried by theradical | | | | | |
|---|---|---|---|---|---|
| Monovalent | | Divalent | | Trivalent | |
| Ammonium | $NH_4^{+1}$ | Calcium | $Ca^{2+}$ | Ferric | $Fe^{3+}$ |
| Sodium | $Na^{+1}$ | Magnesium | $Mg^{2+}$ | Aluminium | $Al^{3+}$ |
| Potassium | $K^{+1}$ | Ferric | $Fe^{2+}$ | | |
| Lithium | $Li^{+1}$ | Zinc | $Zn^{2+}$ | | |
| Cupric | $Cu^{+1}$ | Cupric | $Cu^{2+}$ | | |
| Silver | $Ag^{+1}$ | Stannous | $Sn^{2+}$ | | |
| | | Plambous | $Pb^{2+}$ | | |

Table 1.6B:Basic radicals or electropositive radicals

| Classification based on charge carried by the radical | | | | | |
|---|---|---|---|---|---|
| Monovalent | | Divalent | | Trivalent | |
| Hydroxide | $OH^{-1}$ | Oxide | $O^{2-}$ | borate | $BO_3^{3-}$ |
| Chloride | $Cl^{-1}$ | Sulfate | $SO_4^{2-}$ | phosphate | $PO_4^{3-}$ |
| Nitrate | $NO_3^{-1}$ | Carbonate | $CO_3^{2-}$ | | |
| Bicarbonate | $HCO_3^{-1}$ | Sulfide | $S^{2-}$ | | |
| Peroxide | $O_2^{-2}$ | | $O_2^{2-}$ | | |
| Permanganate | $MnO_4^{-1}$ | | | | |
| Chlorate | $ClO_3^{-1}$ | | | | |

**1.3 MOLECULAR FORMULA**: Chemical formula that indicates the kinds of atoms and the number of each kind of atoms in a molecule of a compound.Example $H_2SO_4$ is the molecular formula of sulfuric acid.In other words, the symbolic representation of a chemical compound is called its formula.

How to write the molecular formula of a compound?

The molecular formula of a chemical compound can be written using criss-cross method.Following steps are followed to write the molecular formula

i) Write radicals of compounds positive radical to the left and negative radicals to the right.
ii) Drop charge sign and write only number called valency numbers.
iii) Criss-Cross these valency numbers.
iv) Write these valency numbers of the combining radicals in simple ratio to the right bottom of radical.
v) Write radicals closely to get the molecular formula of the compound.

Table 1.7: Illustration of writing molecular formula of compound with examples

| Step | Example 1 | | Example 2 | | Example 3 | | Example 4 | |
|---|---|---|---|---|---|---|---|---|
| i) | $Na^{1+}$ Sodium | $OH^{1-}$ hydroxide | $Fe^{3+}$ Ferric | $O^{2-}$ oxide | $Al^{3+}$ Aluminium | $OH^{1-}$ hydroxide | $Ca^{2+}$ Calcium | $CO_3^{2-}$ carbonate |
| ii) | 1: 1 | | 3 :2 | | 3 : 1 | | 2 : 2 | |
| iii) | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 2 |
| iv) | $Na_1$ | $OH_1$ | $Fe_2$ | $O_3$ | $Al_1$ | $(OH)_3$ | $Ca_1$ | $(CO_3^{2-})_1$ |
| v) | NaOH | | $Fe_2O_3$ | | $Al(OH)_3$ | | $CaCO_3$ | |

**Significance of molecular formula:**

Molecularformula of a compound gives both qualitative and quantitative information:

1. Qualitative information

   Molecularformula of a compound represents name of particular compound and distinguish it from rest of compounds.

   NaCl is Sodium chloride and $NaClO_3$ is Sodium chlorate.

2. Quantitative information
   Though, molecularformula represents one molecule of the compound. It signifies one mole compound that contains 6.023 x $10^{23}$ molecules of the compound.

Table 1.8: Qualitative and Quantitative significance of Molecularformula

| Compound | Molecularformula | Quantity<br>1 mol compound = 6.023 x $10^{23}$ molecules of compound |
|---|---|---|
| Sodium hydroxide | NaOH | One mole NaOH = 1 mol NaOH<br>= 6.023 x $10^{23}$ NaOH molecules |

## 1.4 CALCULATION OF MOLECULAR MASS AND PERCENTAGE COMPOSITION

**1.4.1 Molecular mass**: Molecular mass of a substance is the sum of atomic masses of all atoms contained in single molecule. It is calculated by adding the atomic masses of all the atoms present in one molecule of a chemical compound.

It is illustrated using some examples.

1. The molecular mass of $H_2SO_4$can be calculated as(Given atomic mass g/mol: H=1, O=16, S=32).
   $H_2SO_4$
   = [(2 x Atomic mass H) + (1 x Atomic mass S) + (4 x Atomic mass O)]
   = [(2 x 1) + (1 x 32)+ (4 x16)]g/mol,
   = [2 + 32 + 64] g/mol,
   = 98 g/mol $H_2SO_4$
2. The molecular mass of $H_2O$ can be calculated as (Given atomic mass g/mol: H = 1, O = 16).
   $H_2O$
   = [(2 x Atomic mass H) + (1 x Atomic mass O)]
   = [(2 x 1) + (1 x 16)] g/mol,
   = [2 + 16] g/mol
   = 18 g/mol $H_2O$

### 1.4.2 Percentage composition of a chemical compound:

The percentage by mass of each element in a given molecule of chemical compound is described as percentage composition.It is calculated by following steps

i) Calculate the molecular mass of the compound
ii) Calculate the percentage of each element by applying the following formula

$$\text{Percentage of element} = \frac{\text{(Total mass of element in a molecule)}}{\text{Molecular mass}} \times 100$$

Example: Find the percentage composition of a) $H_2SO_4$ b) $CaCO_3$

a) Percentage composition of $H_2SO_4$

Step i) Molecular mass of $H_2SO_4$

= [2x1+1x32+4x16] g/mol = 98 g/mol $H_2SO_4$(as calculated above)

Step ii) Percentage of each element using formula

$$H \text{ \% age in } H_2SO_4 = \frac{2}{98} \times 100 = 2.04 \text{ \% H}$$

$$S \text{ \% age in } H_2SO_4 = \frac{32}{98} \times 100 = 32.65 \text{ \% S}$$

$$O \text{ \% age in } H_2SO_4 = \frac{64}{98} \times 100 = 65.30 \text{ \% O}$$

b) Percentage composition of$CaCO_3$

Step i) Molecular mass of $CaCO_3$

= [1x40+1x12+3x16] g/mol = 100 g/mol $CaCO_3$

Step ii) Percentage of each element using formula

$$Ca \text{ \% age in } CaCO_3 = \frac{40}{100} \times 100 = 40 \text{ \% Ca}$$

$$C \text{ \% age in } CaCO_3 = \frac{12}{100} \times 100 = 12 \text{ \% C}$$

$$O \text{ \% age in } CaCO_3 = \frac{48}{100} \times 100 = 48 \text{ \% O}$$

**Questions for Revision**

1. The branch of chemistry that deals with study of laws of chemical combinations and rate of reaction and factors affect rate is called ___________ chemistry.

a) Physical b) Inorganic c) Organic d) Pharmaceutical

2. The metal that exist in liquid state at room temperature is ________

a) Au b) Hg c) Ag d) Pt

3. The non metal that exist in liquid state at room temperature is ________

a) Diamond b) Bromine c) Chlorine d) Sulfur

4. Total number of acidic and basic radicals in the potassium sulfate

a) 1 b) 2 c) 3 d) 4

5. Choose odd one

a) Iron b) Common salt c) Air d) Coke

6. The percentage of calcium in calcium carbonate will be

a) 100% b) 48% c) 12% d) 40%

**Short answer questions**

1. Define Chemistry.
2. Define Organic chemistry.
3. What do you understand by Physical chemistry?
4. Define Inorganic chemistry.
5. What is a molecular formula?
6. Give two examples to each solids, liquids and gases.
7. Define the following.
   a) Elements
   b) Compounds
   c) Mixtures
   d) Atom
   e) Molecule
   f) Natural solution
8. Write the molecular formula of following compounds
   i) Sodium carbonate
   ii) Calcium bicarbonate
   iii) Magnesium hydroxide
   iv) Zinc sulfate
   v) Aluminium chloride
   vi) Ferric hydroxide
   vii) Potassium nitrate
9. Give two examples to each.
   i) Element
   ii) Compound
   iii) Mixture
   iv) Atom
   v) Molecule.
10. Write the symbols of following elements: Iron, Copper, Nickel, Lead, Gold, Tin, Mercury, Silver, and Iodine.
11. Write the molecular formula of following compounds
   i) Sodium carbonate
   ii) Calcium bicarbonate
   iii) Magnesium hydroxide
   iv) Zinc sulfate
   v) Aluminium chloride
   vi) Ferric hydroxide
   vii) Potassium nitrate.

12. Identify the acidic and basic radicals in the following
    i) $MgCl_2$
    ii) $CaSO_4$
    iii) $Fe(OH)_2$
    iv) CuO
    v) KOH
13. Write the chemical names for the following compounds
    i) $Cu(OH)_2$
    ii) $FeSO_4$
    iii) $MgCl_2$
    iv) $NaHCO_3$
    v) $K_2CO_3$

**Long answer questions:**

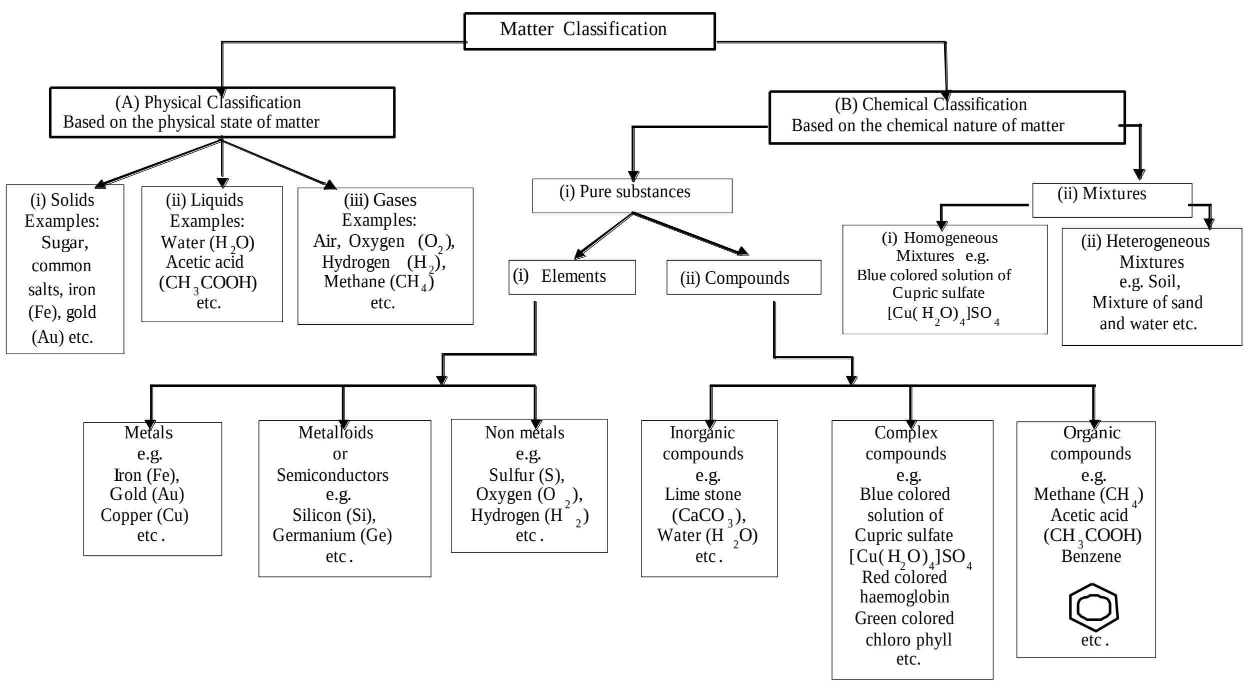
14. How atoms are differing from ions? Explain.
15. What is Chemistry? Discuss its importance.
16. What is matter? How matters are classified based on physical state? Explain.
17. How matters are classified based on chemical nature? Explain.
18. Distinguish solid, liquid and gas.
19. How are elements represented? Explain with significance with examples.
20. State difference between compound and mixture.
21. Calculate the molecular mass and mention number of acidic and basic radicals of followings (for atomic mass of elements refer table 1.4 )
    i) $CaCl_2$
    ii) $Fe(OH)_2$
    iii) $KHCO_3$
    iv) $FeSO_4$
    v) $Mg(HCO_3)_2$
22. Calculate the percentage composition of following (for atomic mass of elements refer table 1.4 )
    i) $CaCO_3$
    ii) $C_2H_5OH$
    iii) $NH_2CONH_2$
    iv) $CH_3COOH$
    v) $MgCl_2$
23. Assignment: Classify the following substances and write in appropriate place in the table given below.
    Glass, bromine, iron, methane, vinegar, silicon, carbon dioxide, water, kerosene, soil, air, germanium, gold, silver, mercury, brass, oil, common salt, washing soda, baking soda, steel.

| Physical classification | Chemical classification | | | | |
|---|---|---|---|---|---|
| | Element | Metalloid | Compound | Mixture | |
| | | | | homogeneous | heterogeneous |
| Solids | | | | | |
| Liquids | | | | | |
| Gases | | | | | |

**Answer to objective type questions:**

| | | | | | |
|---|---|---|---|---|---|
| **1.** | a | **2.** | b | **3.** | b |
| **4.** | c | **5.** | c | **6.** | d |

Chart 1.1



# UNIT - 2

## STRUCTURE OF ATOM

**Learning Objectives:** By learning this unit students will be able to:

- understand atom and their fundamental particles along with namesof discoverer
- understand principles and laws on which structure of atom is established
- describe the meaning of shells and sub shells of atom of elements,
- describe the structure of atom in terms of electronic configuration.
- predict properties of elements.

### 2.1 INTRODUCTION TO ATOMIC STRUCTURE

Matter is made up of extremely small particles called atoms.John Dalton postulated that atom is indivisible particle of an element that cannot be further divided. But at the end of $19^{th}$centuryvarious scientific experiments have proved that atom is made up of various sub atomic particles hence it can be divided. The scientists were able to find the existence of several sub atomic particles, but the three particles namely electron (e), proton (p) and neutron (n) are regarded as the fundamental particles of atom.

**According to the modern concept, an atom has two parts**

i) **Nucleus**:In 1911 L. Rutherford discovered the nucleus of atom. It is the central part of the atom containing positively charged protons in extremely small volume. In 1932 J. Chadwick confirmed the existence of neutral sub atomic particle having mass equal to mass of hydrogen atom called neutron along with protons in the nucleus of an atom. The net charge on nucleus is positive. The magnitude of the charge is equal to the number of protons present in it. The entire mass of atom is due to its nucleus. Protons and Neutrons are collectively known as nucleons.

ii) **Extra nuclear part**:The part of atom around the nucleus in which electrons revolve is called extra nuclear part. Electrons are present in the extra nuclearpart. The number of electrons in extra nuclear part is equal to the number of protons in the nucleus.Since electron have negligible mass, the extra nuclear part does not contribute towards mass of the atom.

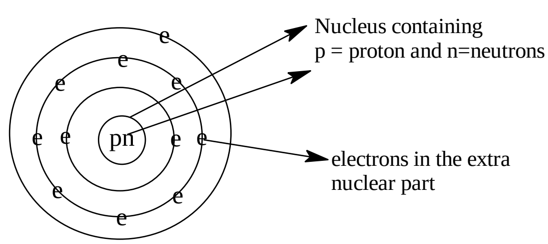



Fig 2.1 Main two parts of atom

## 2.2 FUNDAMENTAL PARTICLES OF ATOM

i) **Electron ($_{-1}e^0$)**: In 1897 Sir J.J. Thomson discovered a universal sub atomic particle called electron by studying properties of cathode rays in discharge tube.

a) Electron carry one unit negative charge ($-1.602 \times 10^{-19}$C = -1 unit negative charge).

b) It has a mass equal to 1/1837$^{th}$ the mass of one atom of hydrogen ($9.1 \times 10^{-31}$ kg).

c) It is essential constituent of all atoms. Hence, it is universal particleand it can be represented as $_{-1}e^0$.

ii) **Proton($_{+1}p^1$)**: In 1886, Goldstein discovered protons by studying properties of anode rays in discharge tube. Protons are positively charged sub atomic particles.

a) Proton has one unit positive charge ($1.602 \times 10^{-19}$C = +1 unit positive charge).

b) It's mass nearly equal to the mass of one atom hydrogen ($1.63 \times 10^{-27}$ kg).

c) It is essential constituent of all atoms. Hence, it is universal particle and it can be represented as $_{+1}p^1$.

iii) **Neutron($_0n^1$)**:In 1932 J. Chadwick experimentally concluded the existence of neutral sub atomic particle having slightly heavier than mass of a proton and no charge by bombardment of beryllium atom's nucleus with alpha (α) particles.

$$_4Be^9 + {_2^4He^{++}} \rightarrow {_6C^{12}} + {_0n^1}$$

Beryllium atom + alpha (α) particle → Carbon atom + neutron

- Protons and Neutrons are almost of same mass.
- The mass of proton is approximately 1837 times greater than that of an electron.

Table 2.1: Characteristics of fundamental subatomic particles

| No | Particle | Discoverer | Charge in C | | Mass in kg | | e/m value C.kg$^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | absolute | relative | absolute | relative | |
| 1. | Electron ($_{-1}e^0$) | J J Thomson | $1.602 \times 10^{-19}$ | -1 | $9.1 \times 10^{-31}$ | 1/1837 | $1.76 \times 10^{11}$ |
| 2. | Proton($_{+1}p^1$) | Goldstein | $1.602 \times 10^{-19}$ | +1 | $1.63 \times 10^{-27}$ | 1 | $9.83 \times 10^{7}$ |
| 3. | Neutron ($_0n^1$) | J Chadwick | 0 | 0 | $1.67 \times 10^{-27}$ | 1 | 0 |

## 2.3 BOHR'S MODEL OF ATOM

In 1913, Neil'sBohr put forward the new model of atomic structure.This atomic model is based upon the quantum theory of energy.

The main postulates of Bohr'smodel are:

1. Electrons revolve around the nucleus in certain fixed circular paths called orbits or shells.
2. Each orbit has a definite energy and therefore known as stationary energy level or shell.

3. These orbits are numbered as 1.2.3.4….. or designated as K, L, M, N….. starting from the shell next to the nucleus.
4. As long asan electron remains in a particular shell, it neither emitsnor absorbs any energy i.e. the energy of an electron in a given orbit is fixed (or quantized).Such orbits are called stationary energy states.
5. An electron can make a transition from a stationary state of higher energy $E_2$ to a stationary state of lower energy $E_1$ and in doing so it emits energy.Similarly, on absorbing the energy, the electron makes transition from lower energy state $E_1$ to higher energy state$E_2$.

   Such that, $\Delta E = E_1 - E_2 < 0$ Transition involve emission of energy

   $\Delta E = E_1 - E_2 > 0$ Transition involve absorption of energy

   $\Delta E = E_1 - E_2 = nh\upsilon$, Where n = 1,2,3,….., h = Planck's constant, $\upsilon$ = frequency
6. Only those orbits are allowed for which the angular momentum (mvr) of the electron is integral multiple of h/2π. Thus,

   Angular momentum of electron = mvr =nh/2π, Where n=1,2,3,4……..

As per the Bohr's model an orbit indicates the exact position of electron in an atom.It is defined as" the definite circular path around the nucleus in which the electron revolves without losing any energy.". It is circular in shape and it represents the two dimensional motion of electron.Orbits are used to determine the energy levels of electrons in an atom.

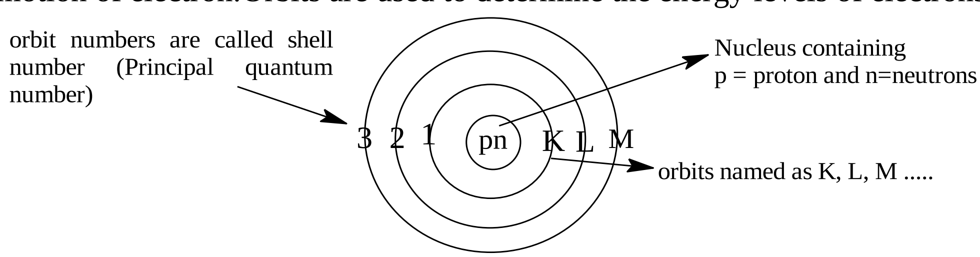



Fig 2.2 Bohr model of atom

**2.3.1 Atomic number**: The atomic number of an atom element is defined as the total number of protons present in the nucleus of an atom. It is denoted by Z.An atomic number is the identity of an atom.Changing the atomic number means changing the atom.

Atomic number Z= number of protons= number of electrons in neutral atom

Table 2.1: Atomic number of some elements

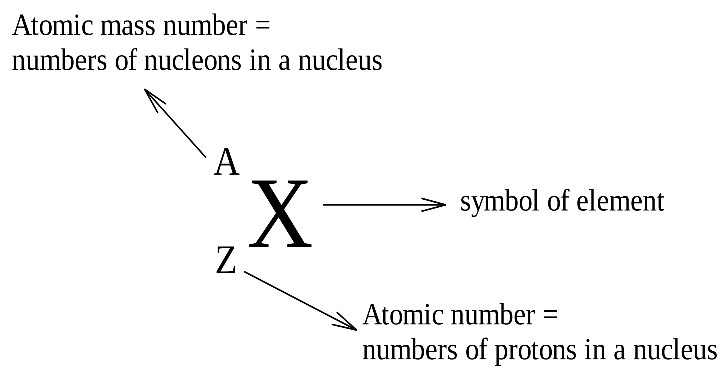
| **Sr. No** | **Symbol** | **Atomic number(Z)** | **Sr. No** | **Symbol** | **Atomic number(Z)** |
|---|---|---|---|---|---|
| 1 | H | 1 | 16 | S | 16 |
| 2 | He | 2 | 17 | Cl | 17 |
| 3 | Li | 3 | 18 | Ar | 18 |
| 4 | Be | 4 | 19 | K | 19 |
| 5 | B | 5 | 20 | Ca | 20 |
| 6 | C | 6 | 21 | Sc | 21 |
| 7 | N | 7 | 22 | Ti | 22 |

| | | | | | |
|---|---|---|---|---|---|
| 8 | O | 8 | 23 | V | 23 |
| 9 | F | 9 | 24 | Cr | 24 |
| 10 | Ne | 10 | 25 | Mn | 25 |
| 11 | Na | 11 | 26 | Fe | 26 |
| 12 | Mg | 12 | 27 | Co | 27 |
| 13 | Al | 13 | 28 | Ni | 28 |
| 14 | Si | 14 | 29 | Cu | 29 |
| 15 | P | 15 | 30 | Zn | 30 |

**2.3.2 Mass number:** As already discussed, the nucleus of an atom contains protons and neutrons.The mass number of an atom is defined as the sum or total number of protons (p) and neutrons (n) present in the nucleus of an atom. It is denoted by A.

$$A=p+n$$

### 2.3.3 Representation of an atom




Example

Nitrogen is written as

$$^{14}_{7}N$$

Where 14 is atomic mass number and 7 is atomic number

### 2.3.4 Calculation of number of electrons,protons and neutrons:

Atomic number and mass number of an elementthe number of electrons, protons and neutrons can be calculated.

Let, e = number of electrons, p = number of protons, n = number of neutrons.

i) In case of an atom,
   Atomic number = Z = p= e(thus, atom is electrically neutral).
   Atomic mass number = A = p +n, =>n = A-Z.
ii) In case of anion,
   Z =p≠ e(p<e) => atom is negatively charged hence, e= Z + |charge|,
   A = p +n, thus, n = A-Z.
iii) For cation,
   Z = p ≠ e(p >e) => atom is positively charged hence, e = Z – |charge|

$A = p + n$ thus, $n = A - p$

Example: Calculate the no. of electron, proton and neutron in following:

a) $^{14}N_7$,
b) $^{40}Ca_{20}{}^{2+}$,
c) $^{127}I_{54}{}^{-}$

Solution:

a) In case of N atom,
A= 14, Z= 7, p = Z = 7, e = p = 7, n= A-Z= 14-7= 7
b) In case of $Ca^{2+}$ ion,
A= 40, Z= 20, p = z= 20, e = Z – charge = 20 – 2 = 18, n= A-Z= 40 – 20= 20.
c) In case of $I^-$ ion,
A= 127, Z= 54, P = z= 54. e = Z + charge = 54 + 1= 55 and
n = A-Z = 127-54= 73

## 2.4 ISOTOPES, ISOBARS, ISOTONES

**2.4.1 Isotopes:** Atoms of same element having same atomic number but different mass number are called isotopes. Isotopes have same chemical properties but different physical properties.

Table 2.2:Some examples of isotopes are

| No | Element | Isotopes | | |
|---|---|---|---|---|
| 1 | H | $_1H^1$(Protium) | $_1H^2$(Deuterium) | $_1H^3$(Tritium) |
| 2 | C | $_6C^{12}$ | $_6C^{13}$ | $_6C^{14}$ |
| 3 | N | $_7N^{14}$ | $_7N^{15}$ | |
| 4 | O | $_8O^{16}$ | $_8O^{17}$ | |
| 5 | Cl | $_{17}Cl^{35}$ | $_{17}Cl^{37}$ | |

**2.4.2 Isobars**:Atoms of different elements having same mass number but different atomic number are called isobar. They have same number of nucleons (protons + neutrons) but different number of protons. The chemical properties of isobars are widely differing. Their physical properties may be identical.

Table 2.3:Some examples of isobars are

| No | Isobars | Z | A | e = Z | p = Z | n = A - Z |
|---|---|---|---|---|---|---|
| 1 | $_{18}Ar^{40}$ | 18 | 40 | 18 | 18 | 40 – 18 = 22 |
| 2 | $_{19}K^{40}$ | 19 | 40 | 19 | 19 | 40 – 19 = 21 |
| 3 | $_{20}Ca^{40}$ | 20 | 40 | 20 | 20 | 40 – 20 = 20 |

**2.4.3 Isotones:** Atoms of different elements having same number of neutrons but different atomic number and mass number are called isotones.

Table 2.4:Some examples of isotones are

| No | Isotones | Z | A | e = Z | p = Z | n = A - Z |
|---|---|---|---|---|---|---|
| 1 | $_6C^{14}$ | 6 | 14 | 6 | 6 | 14 – 6 = 8 |
| 2 | $_7N^{15}$ | 7 | 15 | 7 | 7 | 15 – 7 = 8 |
| 3 | $_8O^{16}$ | 8 | 16 | 8 | 8 | 16 – 8 = 8 |

## 2.5 CONCEPT OF ORBITAL (Wave nature of electron):

**a)** Particle and Wave nature of electron: In 1924, de Broglie proposed a relation between wave nature (λ) associated with moving particles. According to de Broglie hypothesis wave associated with an electron (λ) can be expressed as:

$$\left.\begin{array}{c}\text{wave associated}\\ \text{with electron } (\lambda)\end{array}\right\} = \frac{h}{mv}$$

where, h = Planck's constant = $6.626 \times 10^{-34}$ Js
m = electron mass and v = velocity of electron

The wave nature associated with macroscopic particle is very small and becomes insignificant. However, electron wave nature is considerable and has practical utility.

**b)** Heisenberg's uncertainty principle

It states that, it is impossible to determine momentum (mv) and position (x) of moving subatomic particles more accurately and simultaneously.

Let Δx = uncertainty in position of electron and Δp = Δmv = uncertainty in momentum of electron, then

$$\Delta p\,.\Delta x \;=\; \Delta mv\,.\Delta x \;\geq\; \frac{h}{4\pi}$$

where, h = Planck's constant = $6.626 \times 10^{-34}$ Js
m = electron mass and v = velocity of electron

According to quantum mechanics, an atomic orbital is a mathematical function that describes the wave like behavior of electron in the atom. An orbital is defined as the three dimensional space around the nucleus where the probability of finding the electron is maximum. An orbital is commonly represented by an electron cloud. It represents the 3-D motion of an electron in the atom. The probability of finding the electron is never zero even at large distances from the nucleus. Atomic orbitals allow the atoms to make covalent bonds. An orbital can contain two electrons with opposite spin. The most commonly filled orbitals are s,p,d, and f.

All s orbitals are spherical.

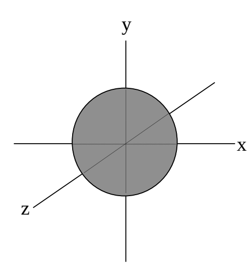



Fig 2.2 s orbital spherical shape

There are three p orbitals viz. $p_x$, $p_y$, and $p_z$are dumbbell shaped.

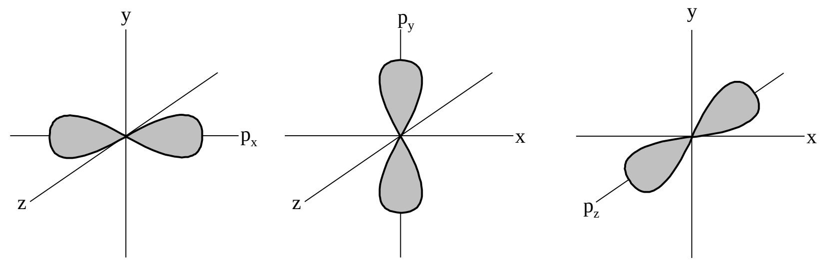



Fig 2.3 p orbitals dumbbell shape

There are 5 d orbitals viz. $d_{xy}$,$d_{yz}$, $d_{zx}$, $d_{x2-y2}$, and $d_{z2}$. The shape of d orbitals is double dumbbell.

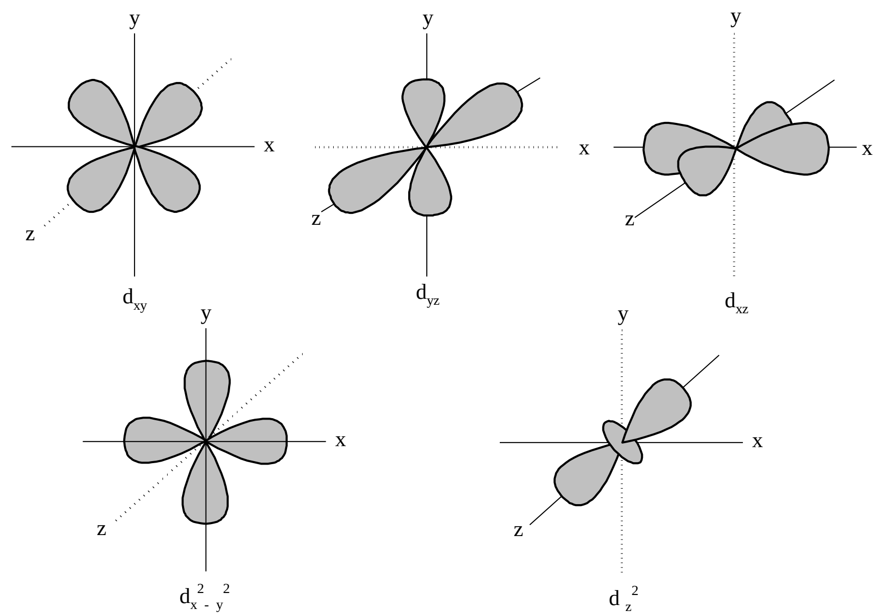



Fig 2.4 d orbitals double dumbbell shape

Table 2.5: Difference between orbit and orbital

| Sr. No. | Orbit | Orbital |
|---|---|---|
| 1 | Orbit is well defined circular path followed by electron around the nucleus | Orbital is the region of space around the nucleus where the probability of finding an electron is maximum |
| 2 | Orbit is represents the two-dimensional or planar motion of electron around the nucleus | Orbital represents the three dimensional motion of electron around the nucleus |
| 3 | All orbits are circular in shape | Different orbitals have different shapes |
| 4 | Orbits do not have any directional character | With the exception of s orbital, all other orbitals have directional character |
| 5 | The maximum number of electrons in an Orbit is $2n^2$ | The maximum number of electrons in an orbital is 2 having opposite spin in particular direction of orbital. |

25.

## 2.6 PRINCIPLES OF FILLING ELECTRONS IN VARIOUS ORBITALS:

**2.6.1 Aufbau principle**: The German term "Aufbau" means building up or construction. The Aufbau principle explains how electrons are getting filled up in orbitals of various shells in an atom. It can be used to describe the locations and energy levels of every electron in a given atom.The principle states that"In the ground state of atom electrons are filled in the increasing order of energy of orbitals."The increasing order of energies of various orbitals is 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, ….

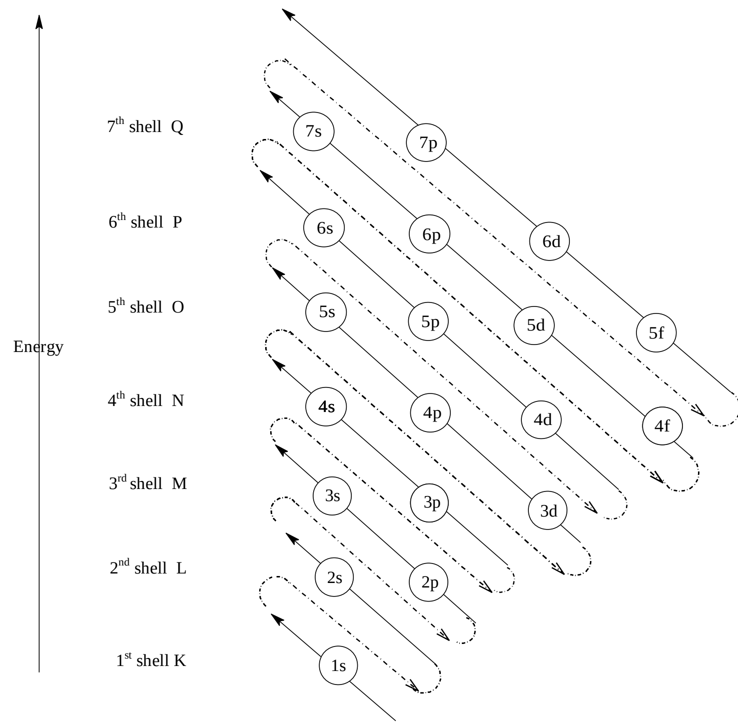



Fig 2.5 Aufbau principle

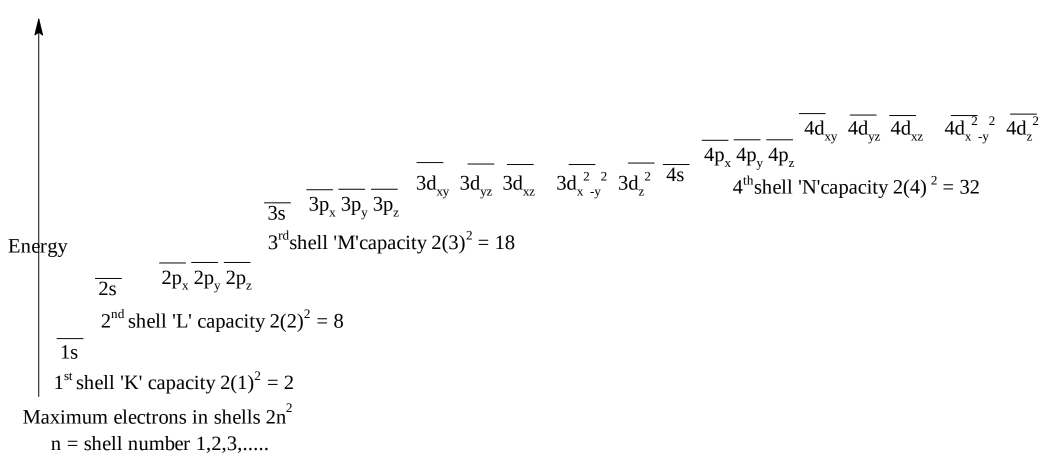



Fig 2.6 Increasing energies of shell and orbitals digramatic illustration

**2.6.2 Pauli's exclusion principle:**This principle was given by Wolfgang Pauli in 1925.According to this principle,Maximum of two electrons occupies atomic orbitals of shell and in accordance with their energy opposite spins.

The electron with clock wise spin is represented by +½ or ↑ and that with anticlock wise spin is represented by-½ or ↓.

**2.6.3 Hund's rule of maximum multiplicity:**It states that "the paring of electronsin the orbitals of same subshell does not take place until each orbital of the subshell has got one electron each or singly filled first."

For example, there are three p, five d and seven f orbitals. Pairing of electrons in the psub shell starts with the addition of 4[th]electron.

| Elements | Electron distribution in shells and their orbitals | | | | |
|---|---|---|---|---|---|
| Shells | K | L | | | |
| $_1H$ | ↑ | | | | |
| Orbitals | $1s^1$ | | | | |
| $_2He$ | ↑↓ | | | | |
| Orbitals | $1s^2$ | | | | |
| $_3Li$ | ↑↓ | ↑ | | | |
| Orbitals | $1s^2$ | $2s^1$ | $2p_x^0$ | $2p_y^0$ | $2p_z^0$ |
| $_4Be$ | ↑↓ | ↑↓ | | | |
| Orbitals | $1s^2$ | $2s^2$ | $2p_x^0$ | $2p_y^0$ | $2p_z^0$ |
| $_5B$ | ↑↓ | ↑↓ | ↑ | | |
| Orbitals | $1s^2$ | $2s^2$ | $2p_x^1$ | $2p_y^0$ | $2p_z^0$ |
| $_6C$ | ↑↓ | ↑↓ | ↑ | ↑ | |
| Orbitals | $1s^2$ | $2s^2$ | $2p_x^1$ | $2p_y^1$ | $2p_z^0$ |
| $_7N$ | ↑↓ | ↑↓ | ↑ | ↑ | ↑ |
| Orbitals | $1s^2$ | $2s^2$ | $2p_x^1$ | $2p_y^1$ | $2p_z^1$ |
| $_8O$ | ↑↓ | ↑↓ | ↑↓ | ↑ | ↑ |
| Orbitals | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^1$ | $2p_z^1$ |
| $_9F$ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑ |
| Orbitals | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^2$ | $2p_z^1$ |
| $_{10}Ne$ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ |
| Orbitals | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^2$ | $2p_z^2$ |

Similarly, the pairing of electrons in the d subshell starts with the addition of 6th electron.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $_{26}Fe$ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑ | ↑ | ↑ | ↑ |
| | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^2$ | $2p_z^2$ | $3s^2$ | $3p_x^2$ | $3p_y^2$ | $3p_z^2$ | $4s^2$ | $3d_{xy}^2$ | $3d_{yz}^1$ | $3d_{xz}^1$ | $(3d_{x^2-y^2})^1$ | $3d_z^1$ |
| $_{27}Co$ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑ | ↑ | ↑ |
| | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^2$ | $2p_z^2$ | $3s^2$ | $3p_x^2$ | $3p_y^2$ | $3p_z^2$ | $4s^2$ | $3d_{xy}^2$ | $3d_{yz}^2$ | $3d_{xz}^1$ | $(3d_{x^2-y^2})^1$ | $3d_z^1$ |
| $_{28}Ni$ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑ | ↑ |
| | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^2$ | $2p_z^2$ | $3s^2$ | $3p_x^2$ | $3p_y^2$ | $3p_z^2$ | $4s^2$ | $3d_{xy}^2$ | $3d_{yz}^2$ | $3d_{xz}^2$ | $(3d_{x^2-y^2})^1$ | $3d_z^1$ |
| $_{29}Cu$* | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ |
| | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^2$ | $2p_z^2$ | $3s^2$ | $3p_x^2$ | $3p_y^2$ | $3p_z^2$ | $4s^1$ | $3d_{xy}^2$ | $3d_{yz}^2$ | $3d_{xz}^2$ | $(3d_{x^2-y^2})^2$ | $3d_z^2$ |
| $_{30}Zn$ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ | ↑↓ |
| | $1s^2$ | $2s^2$ | $2p_x^2$ | $2p_y^2$ | $2p_z^2$ | $3s^2$ | $3p_x^2$ | $3p_y^2$ | $3p_z^2$ | $4s^2$ | $3d_{xy}^2$ | $3d_{yz}^2$ | $3d_{xz}^2$ | $(3d_{x^2-y^2})^2$ | $3d_z^2$ |

**2.6.4 Electronic configuration of atoms:** The occupancy of electrons in accordance with their energiesin various orbitals (or subshells) in an atom is known as electronic configuration.Electronic configuration is the standard notation used to describe the electronic structure of an atom. It allows us to understand the energy of electrons. The electronic configuration of an atom gives us a better understanding of its bonding ability and chemical properties.

Table 2.5: Electronic arrangements in various shells of an atom

| Sr. No. | Element | Z (Atomic number) | Electronic arrangements | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | K (1) | L (2) | | M (3) | | | N (4) | | | |
| | | | s | s | p | s | p | d | s | P | d | f |
| 1 | H | 1 | 1 | | | | | | | | | |
| 2 | He | 2 | 2 | | | | | | | | | |
| 3 | Li | 3 | 2 | 1 | | | | | | | | |
| 4 | Be | 4 | 2 | 2 | | | | | | | | |
| 5 | B | 5 | 2 | 2 | 1 | | | | | | | |
| 6 | C | 6 | 2 | 2 | 2 | | | | | | | |
| 7 | N | 7 | 2 | 2 | 3 | | | | | | | |
| 8 | O | 8 | 2 | 2 | 4 | | | | | | | |
| 9 | F | 9 | 2 | 2 | 5 | | | | | | | |
| 10 | Ne | 10 | 2 | 2 | 6 | | | | | | | |
| 11 | Na | 11 | 2 | 2 | 6 | 1 | | | | | | |
| 12 | Mg | 12 | 2 | 2 | 6 | 2 | | | | | | |
| 13 | Al | 13 | 2 | 2 | 6 | 2 | 1 | | | | | |
| 14 | Si | 14 | 2 | 2 | 6 | 2 | 2 | | | | | |
| 15 | P | 15 | 2 | 2 | 6 | 2 | 3 | | | | | |
| 16 | S | 16 | 2 | 2 | 6 | 2 | 4 | | | | | |
| 17 | Cl | 17 | 2 | 2 | 6 | 2 | 5 | | | | | |
| 18 | Ar | 18 | 2 | 2 | 6 | 2 | 6 | | | | | |
| 19 | K | 19 | 2 | 2 | 6 | 2 | 6 | | 1 | | | |
| 20 | Ca | 20 | 2 | 2 | 6 | 2 | 6 | | 2 | | | |
| 21 | Sc | 21 | 2 | 2 | 6 | 2 | 6 | 1 | 2 | | | |
| 22 | Ti | 22 | 2 | 2 | 6 | 2 | 6 | 2 | 2 | | | |
| 23 | V | 23 | 2 | 2 | 6 | 2 | 6 | 3 | 2 | | | |
| 24 | Cr* | 24 | 2 | 2 | 6 | 2 | 6 | 5 | 1 | | | |
| 25 | Mn | 25 | 2 | 2 | 6 | 2 | 6 | 5 | 2 | | | |
| 26 | Fe | 26 | 2 | 2 | 6 | 2 | 6 | 6 | 2 | | | |
| 27 | Co | 27 | 2 | 2 | 6 | 2 | 6 | 7 | 2 | | | |
| 28 | Ni | 28 | 2 | 2 | 6 | 2 | 6 | 8 | 2 | | | |
| 29 | Cu* | 29 | 2 | 2 | 6 | 2 | 6 | 10 | 1 | | | |
| 30 | Zn | 30 | 2 | 2 | 6 | 2 | 6 | 10 | 2 | | | |

* Exceptional electronic arrangements

**Questions for Revision**

1. ______________ fundamental particle is having maximum charge to mass ratio.

a) proton b) electron c) neutron d) none

2. Atoms of different elements having same atomic masses are called_____________

a) isotopes b) isobars c) isotones d) all

3. Electronic distribution in sodium atom (A = 11) is__________________

a) 2, 8, 1 b) 2,1,8 c) 3,3,5 d) 4,4,3

4. Electrons occupy atomic orbitals in the increasing order of their energy is ______ principle/rule.

a) Hund's b) de Broglie c) Aufbau's d) Heisenberg's

5. Shape of 's' orbital is ________

a) spherical b) dumbbell c) double dumbbell d) zig-zag

6. The maximum number of electrons present in the second shell_______

a) 2 b) 32 c) 18 d) 8

7. Number of electrons, protons in an atom of argon (Ar = 18) respectively

a) 18 & 18 b) 36 & 18 c) 9 & 18 d) 18 & 9

8. The heaviest fundamental particle is ______

a) electron b) proton c) neutron d) orbital

9. Simplest state of matter is _______ state.

a) solid b) liquid c) plasma d) gaseous

10. The part of atom which is less denser is _______

a) extra nuclear part b) nucleus c) shell d) orbital

11. If e = charge, and m = mass of electron of sub atomic particles, then which sub atomic particle has lowest value of charge to mass ratio i.e. e/m value?

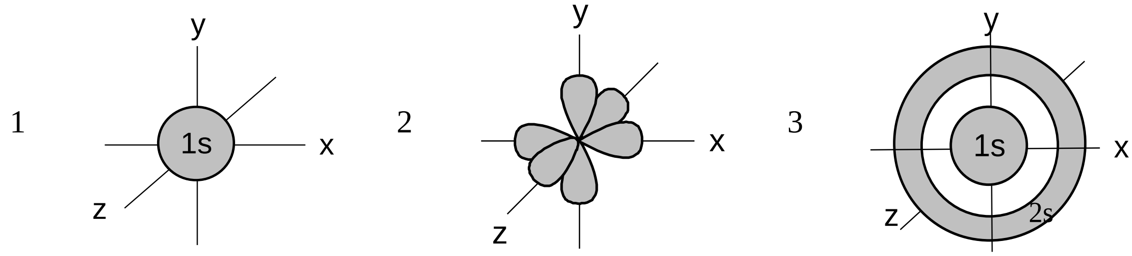
a) electron b) nucleus c) neutron d) proton

12. Electrons are associated with both ______ and _______ character

a) particle only b) wave only c) wave and particle d) none

13. Choose the incorrect statement among the followings?
    a) Electrons were discovered by Sir J J Thomson. These are the result of cathode rays properties.
    b) Study of positive rays lead to the discovery of protons.
    c) Nucleons are relatively lighter than extra nuclear part of atom.
    d) α- particles bombardment with beryllium atom results in the discovery of neutrons.

14. Choose correct orbitals




a) 1 and 2 b) 2 and 3 c) 3 and 1 d) All

15. Bohr's atomic theory is based on _______ theory.

a) classical b) quantum c) wave d) particle

16. Maximum number of electrons ins, p, d and f orbitals respectively.

a) 14, 10, 6 and 2 b) 14, 6, 2 and 10 c) 2, 6, 10 and 14 d) 2, 10, 6 and 14

**Short answer questions**

17. What is the charge on an electron?
18. What is the mass of a proton?
19. Name the scientist who discovered neutron?
20. Define the following
    i) Atomic number (Z).
    ii) Mass number (A).
21. What is an atomic orbital?
22. Define Aufbau's principle.
23. State Hund's rule.
24. Name three isotopes of hydrogen.
25. How many electrons are present in ${}_{92}U^{238}$?

**Long answer type questions**

26. Explain Pauli's exclusion principle.
27. What do you understand by the term – electronic configuration?
28. Name the orbital which does not have directional character.
29. Which electrons take part in bond formation?
30. What is an orbit?
31. Write the name and symbol of that element which has no neutron.
32. Explain the followings with suitable examples:
    i) Isotopes
    ii) Isobars
    iii) Isotones
33. State difference between orbit and orbital.

34. Write the electronic configuration of following atoms
$_{6}C$, $_{24}Cr$, $_{29}Cu$, $_{16}S$, $_{20}Ca$,$_{30}Zn$.
35. Identify isotopes and isobars in the following:
$_{1}H^{2}$, $_{6}C^{13}$, $_{20}Ca^{40}$, $_{1}H^{1}$, $_{19}K^{40}$, $_{6}C^{14}$, $_{1}H^{3}$, $_{18}Ar^{40}$
36. What are different types of orbitals?
37. Calculate A,Z, e, p, and n in the following
$[_{16}S^{32}]^{2-}$, $_{1}H^{1}$, $[_{13}Al^{27}]^{3+}$, $_{7}N^{14}$, $[_{19}K^{39}]^{1+}$,$[_{17}Cl^{35}]^{1-}$, $_{20}Ca^{40}$
38. What are three fundamental particles of an atom? Discuss in brief.
39. Discuss the postulates of Bohr's model of atom.
40. Explain the types of orbitals and their shapes.
41. Draw s orbital, p orbitals.
42. What does electronic arrangement of an atom signifies?
43. Differentiate atom and ion.
44. Write name and electronic arrangement of two elements having octetarrangements.

**Answers to objective type questions:**

| | | | | | |
|---|---|---|---|---|---|
| 1. | b | 2. | b | 3. | a |
| 4. | c | 5. | a | 6. | d |
| 7. | a | 8. | c | 9. | d |
| 10. | b | 11. | c | 12. | c |
| 13. | c | 14. | d | 15. | b |
| 16. | c | | | | |

# UNIT - 3

## CHEMICAL BONDING

**Learning Objectives:** By learning this unit students will be able to:

- understand cause of chemical bonding and types of chemical bonds
- describe the octet arrangement and minimum energy state
- writestructure of few molecules and compounds.
- predict properties of compound.

**3.1 INTRODUCTION CHEMICAL BONDING:** Atoms are generally not capable of free existence, but groups of atoms of the same or different elements can exist as one species.Example $H_2$, $O_2$,$P_4$, $S_8$,$H_2O$.A group of atoms existing together as one species and having characteristic properties is called a molecule.Obviously, there must be some force which holds these atoms together within the molecule.These forces which hold the atoms within the molecule are called chemical bonds.

**3.1.1 Valence electrons and Lewis symbols:**In the formation of a molecule, only the outer shell electrons are involved.They are known as valence electrons.Inner shell electrons are well protected and are generally not involved in the combination process.It is, therefore, quite responsible to consider the outer shell electrons i.e. valence shell electrons while discussing chemical bonds.G.N. Lewis introduced simple symbols to denote the valence shell electrons in an atom.The outer shell electrons are shown as dots surrounding the symbol of the atom.These symbols are known as Lewis symbols or electron dot symbols.These symbols ignore the inner shell electrons.The symbol of elements along with valence electrons in the form of dot or cross is called Lewis symbol. A few examples Lewis symbol are given below:

Table 3.1: Examples Lewis symbol of few elements are shown below:

| Element | H | C | N | O | F |
|---|---|---|---|---|---|
| Symbol | •H | ••C•• | •••N•• | •••O••• | ••••F••• |

**3.2 OCTET RULE**:Atoms form chemical bonds in order to complete their octet i.e. 8 electrons in the valence shell.The octet rule applies for covalent bonding, with a total of eight electrons the most desirable number of unshared or shared electrons in the outer valence shell. For example, carbon has an atomic number of six, with two electrons in shell 1 and four electrons in shell 2, its valence shell. This means that carbon needs four electrons to achieve an octet. Carbon is represented with four unpaired electrons. If carbon can share four electrons with other atoms, its valence shell will be full. Most elements involved in covalent bonding need eight electrons to have a complete valence shell. One notable exception is hydrogen (H) attains doublet when it combines with other elements to form chemical bond.

**3.3 CHEMICAL BOND AND ITS TYPES**:The force that holds two or more atoms together in a molecule is called chemical bond.**Modes of chemical combination**:There are three modes of bond formation between the atoms.These are,

i) **By the transfer of electrons**: The chemical bond which is formed by the complete transfer of one or more electron from one atom to another is termed as ionic bond orelectrovalent bond.
ii) **By sharing of electrons**:The bond which is formed by equal sharing of electrons between two atoms is called covalent bond.In these bonds,electrons are contributed by both atoms.
iii) **Coordinate bond**: When the electrons are contributed by single atom but shared by both in forming the bond,such bond is known as dative bond or co-ordinate bond. Compound having such bonding are generally called complex compounds. Some examples of coordinate compounds are $NH_4^+$ ion, $SO_3$ molecule.

It is important to know that atoms participate in chemical reaction to attain octet (or duplet) electronic arrangement by forming chemical bonds. Therefore bond formation results in minimum energy state and maximum stability to the molecule formed in the reaction.

**3.4 IONIC OR ELECTROVALENT BOND:**The bond which is formed by complete transfer of electrons from one metal atom to another non metallic atom so as to complete their octetand become ionic tohold each other by electrostatic force of attraction called ionic bond. Metallic atom which loose electron (get oxidized) will acquire positive charge and it is called cat ion. Non metallic atom which gain electrons(get reduced) will acquire negativecharge and is known as anion.The electrostatic force of attraction which sets between cat ion and anion is ionic or electrovalent bond. The compounds so formed are called ionic or electrovalent compounds.The number of electrons which an atom loses or gains in the formation of ionic bond is called its electrovalency.

Let M be the metal atom and X be the non metallic atom

1. $M_{(s)} \rightarrow M^{+n}_{(g)} + ne^{-1}$, oxidation of metal to metal ion with electrovalency ‘n’ i.e. number of electrons lost.
2. $X_{(g)} + n\ e^{-1} \rightarrow X^{-n}_{(g)}$, reduction of non metal to form anion with electrovalency ‘n’ i.e. number of electrons gained.
3. $M^{+n}_{(g)} + X^{-n}_{(g)} \rightarrow MX_{(s)}$.$M^{+n}_{(g)}$ and $X^{-n}_{(g)}$ are held by electrostatic force of attraction to form an ionic electrovalent compound$MX_{(s)}$.

**Formation of NaCl moleculeexplanation:**Sodium atoms are electrically neutral,since they have 11numbers of protons and 11 electrons.When sodium atom looses an electron,to attain octet and it acquires one positive charge. Since the numbers of protons are more than number of electrons.

1. $Na_{(s)} \rightarrow Na^{+1}{}_{(g)} + 1\ e^{-1}$. } Oxidation of sodium metal (loss of electrons) to form sodium cation with electrovalency '1', since it has lost an electron.

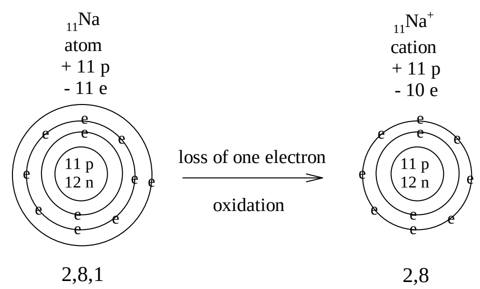



Fig 3.1 Formation of sodium cation

On the other hand,chlorine atom on gaining one electron, the number of electrons becomes more than number of protons thus, the chlorineatom becomes negatively charged called chloride.

2.$\frac{1}{2}\ Cl_{2(g)} + 1\ e^{-1} \rightarrow Cl^{-1}{}_{(g)}$. } Reduction of chlorine atom (gain of electrons) to form chloride anion as it has gained one electron. Thus, electrovalency of chlorine is 1.

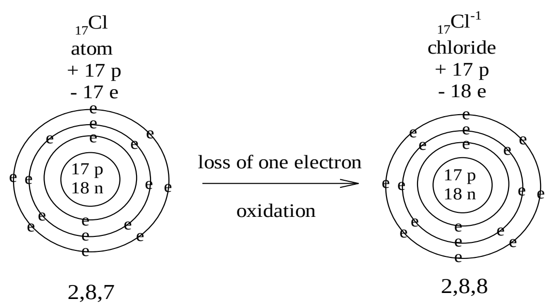
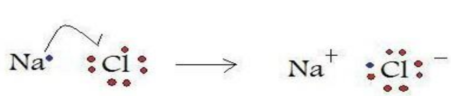



Fig 3.2 Formation of chloride ion (anion)

3. $Na^{+1}{}_{(g)} + Cl^{-1}{}_{(g)} \rightarrow NaCl_{(s)}$. }

Or




The oppositely charged i.e sodium cation and chloride ions so formed attract each other by electrostatic force of attraction. Thus, sodium chloride NaClis formed which is an electrovalent or ionic compound by redox reaction(in which oxidation and reduction take place simultaneously).

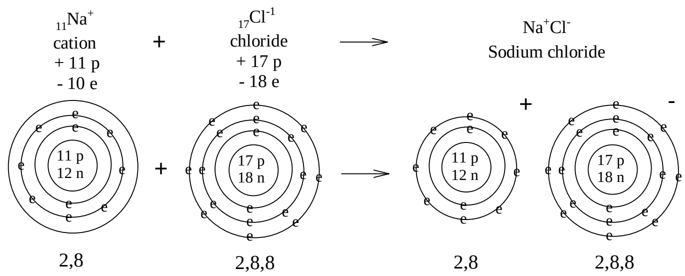



Fig 3.3 Formation of sodium chloride ionic compound

**3.5 COVALENT BOND:** The bond formed between two atoms by mutual sharing of electrons in order to complete their octet or duplet (in case of elements having only one shell) and attain minimum energy state is called covalent bond. Or The bond which is formed by equal contribution ofelectrons by bonding atoms so as to complete their octet or duplet (in case of elements having only one shell) is called covalent bond.The compounds formed by the sharing of electrons between two or more atoms are called covalent compounds.The number of electrons contributed by each atomto form covalent bond is known as its covalency.The covalent bond formed by the mutual sharing of one pair of electrons between the two atoms is called a single bond. This is shown by a single line(-).The covalent bond formed by the mutual sharing of two pair of electrons between the two atoms is called double bond. This is shown by a double line(=).The covalent bond formed by the mutual sharing of three pair of electrons between the two atoms is called triple bond. This is shown by a three parallel lines(≡).

1. **Formation of $H_2$ molecule**:Atomic number of H atom is 1.It has one electron.In the formation of $H_2$ molecule, each atomshare one electron each and acquires 2 electrons(duplet configuration of helium He - an inert gas)in the valence shell which results in minimum energy state.

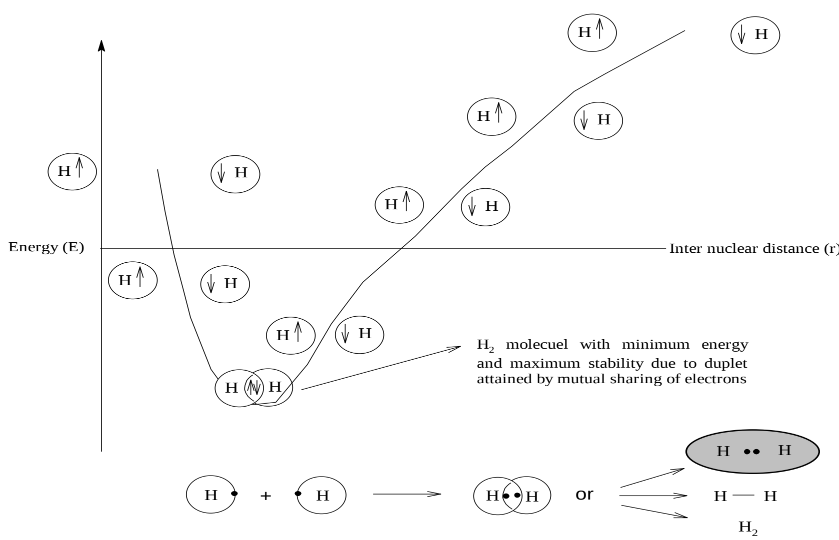



Fig 3.4 Energy diagram of $H_2$ molecuel formation

2 **Formation of $O_2$ molecule**:In the formation of the oxygen molecule, each atom of oxygen forms two bonds to the other oxygen atom, producing the molecule $O_2$.

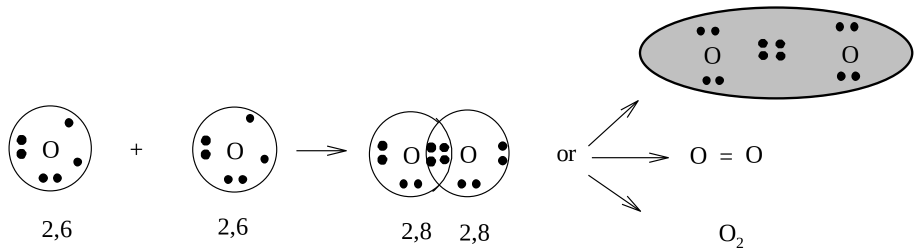



Fig 3.5 Formation of oxygen ($O_2$) meolecule

3 **Formation of $N_2$ molecule**:Each nitrogen atom is able to share three electrons for a total of six shared electrons in the $N_2$ molecule

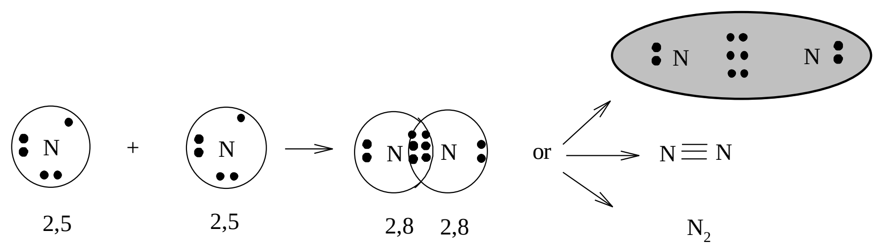



Fig 3.6 Formation of oxygen ($N_2$) meolecule

**3.6 COORDINATE BOND**: When the electrons are contributed by single atom but shared by both in forming the bond, such bond is known as dative bond or co-ordinate bond. Consider the formation of ammonium radical ($NH_4^+$) in ammonium compounds.

$$\ddot{N}H_3 + H^+ \rightarrow NH_4^+$$

Table 3.2: General properties of materials based on the bonding in them:

| Properties | Ionic compounds | Covalent compounds | Metals |
|---|---|---|---|
| 1. Physical state at room temperature | Solids with high<br>a) Density<br>b) Melting point | May be solids with low melting point, or liquids or gases | Solids with high (Except Hg)<br>a) Density<br>b) Melting point |
| 2. Solubility in water | Highly water soluble | Generally water insoluble | Water insoluble |
| 3. Conductance of electric current | Conducts electric current in molten or aqueous solution state due to ion migration, and undergo change in their chemical composition after passage of electric current. | Do not conduct electric current. | Conducts electric current without undergoing any change in the chemical composition after passage of electric current. |

**Questions for Revision**

1. The cause for the chemical bond formation is to acquire

a) octet arrangement b) minimum energy state c) both a & b d) none

2. The cause for the chemical reaction is to

a) form chemical bonds b) acquire minimum energy state c) acquire octet arrangement d) all

3. According to electronic concept oxidation and reduction are ___ & _____respectively.

a) loss of electrons, and gain of electrons b) gain of electrons, and loss of electrons c) only loss of electrons d) none

4. Outer most shell electrons are called

a) valency electrons b) core electrons c) mobile electrons d) both a & c

5. When the electrons are contributed by single atom but shared by bothcombining atoms to form bond in the molecule, such bond is called ______

a) ionic bond b) covalent bond c) coordinate bond d) none

6. The bond formed by the complete transfer of electrons from metal atom to non metal atom is called ________ bond.

a) ionic bond b) covalent bond c) coordinate bond d) none

7. ____ among the following is/are example(s) of covalent compound(s).

a) Methane gas b) Mustered oil c) Water d) All

8. Ionic compound(s) among the following is/are ________.

a) NaCl b) $MgCl_2$ c) KI d) All

9. The number of electrons contributed by each atom to form covalent bond is known as its ________.

a) electrovalency b) covalency c) bonding d) All

10. The molecule which contain respectively single, double, triple covalent bonds are ____, ____ and ______.

a) $N_2$, $O_2$, $Cl_2$. b) $N_2$,$Cl_2$, $O_2$. c) $Cl_2$, $N_2$, $O_2$. d) $Cl_2$, $O_2$, $N_2$.

**Short answer questions**

1. What are valence electrons?
2. How many valence electrons are present in the following:
   N, C, O, H, Cl, Na,
3. What do you understand by Lewis symbols?
4. State Octet rule.
5. What is a chemical bond? What are its types?

6. Write twocompounds to each of the followings
    a) Ionic bond compounds
    b) Covalent bond compounds
    c) Coordinate bond compounds
7. What do you mean by ionic compounds?
8. What is electrovalency?
9. What do you mean by covalent compounds?
10. What is covalency?
11. How many covalent bonds are present in $N_2$ molecule?
12. Which type of bond is present in $CH_4$ molecule?

**Long answer questions**

13. Give the covalency of each atom in the following compounds:
    a) $CH_4$.
    b) $H_2O$.
    c) $NH_3$.
14. Give the electrovalency of each ion in the following ionic compounds:
    a) NaCl
    b) $MgCl_2$.
    c) $Al_2(SO_4)_3$.
15. State difference between ionic and covalent compounds.
16. Define ionic bond. Discuss the formation of ionic bond taking example of NaCl molecule.
17. What are causes of chemical bonding?
18. Ascertain general physical properties of ionic and covalent compounds.
19. Differentiate ionic compounds and metals.
20. Draw the Lewis structure of i) $CH_4$. ii) $NH_3$.
21. Why does a chemical reaction take place? Explain in light of chemical bond formation.
22. What is oxidation?
23. What is reduction?
24. What is redox reaction?
25. Mention two redox reactions from daily life.

**Answers to objective type questions:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | c | 2. | d | 3. | a | 4. | d | 5. | c |
| 6. | a | 7. | d | 8. | d | 9. | b | 10. | d |

# UNIT -4

## SOLUTION

**Learning Objectives:** By learning this unit students will be able to:

- understand mixture and their types and differentiate solution and mixture
- express the concentration of solution in different units, and prepare solution of required concentrations
- understand pH of solution and calculate pH solution.
- classify chemical substances into acidic, basic and neutral based on $P^H$ value.

**4.1 SOLUTION**:Homogeneous mixture of two or more chemically non reacting substances in single phase is called solution. Examples are of solution sugar solution, salt solution etc.The substances forming the solution are called components of the solution.

**4.1.1 Binary Solution**: The solution which has only two components is called binary solution.Sugar solution, salt solutions are the examples of binary solutions.

**4.1.2 Aqueous Solution**: The solution which contains water as a component is called aqueous solution. Sugar solution, salt solutions are the examples of aqueous solutions.

**4.1.3 Dilute Solution**:The solution which contains relatively large amount of solvent is called dilute solution.

**4.1.4 Concentrated Solution:**The solution which contains relatively larger amount of solute is called concentrated solution.

**4.2 SOLUTE:**The component of solution which is present in smaller amount by mass is called solute. Example 1) In sugar solution, sugar is solute. 2) In salt solution, salt is solute.

**4.3 SOLVENT:**The component of solution which is present in larger amount by mass is called solvent. Example 1) In sugar solution, water is solvent. 2) In salt solution, water is solvent.

**4.4 ACID:** The Substance which contains hydrogen or produce (give) hydrogen ions ($H^+$) in its aqueous solution is called acid. e.g. $HCl_{(aq)}$, $H_2SO_{4(aq)}$, $HNO_{3(aq)}$, and $CH_3COOH_{(aq)}$ are common example of acids.

**Basicity of an acid:** The number of replaceable hydrogen atom present in one molecule of acid is called its basicity.

Example:

1) Basicity of HCl is 1, since it produces one hydrogen ion in its aqueous solution.
   $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^{-1}_{(aq)}$.
   Similarly, Basicity of$H_2SO_4$ is 2, since it produces one hydrogen ion in its aqueous solution. $H_2SO_{4\,(aq)} \rightarrow 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$.

Basicity of $HNO_3$ is 1, since it produces one hydrogen ion in its aqueous solution. $HNO_{3\,(aq)} \rightarrow H^+_{(aq)} + NO_3^{1-}{}_{(aq)}$.

Basicity of $CH_3COOH$ is 1 since it produces one hydrogen ion in its aqueous solution. $CH_3COOH_{(aq)} \rightarrow H^+_{(aq)} + CH_3COO^{1-}{}_{(aq)}$.

**4.5 BASE**:The substance which contains hydroxyl group (OH group) or produce (give) hydroxyl ions ($OH^-$) in its aqueous solution is called base. KOH, NaOH and $NH_4OH$ are common example of bases.

**Acidity:** The number of replaceable hydroxyl group present in one molecule of base called its acidity.

Example:

Acidity of KOH is 1, KOH is 1 since it produces one hydroxyl ion in its aqueous solution. $KOH_{(aq)} \rightarrow K^+_{(aq)} + OH^{1-}{}_{(aq)}$.

Acidity of NaOH is ,NaOH is 1, since it produces one hydroxyl ion in its aqueous solution. $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^{1-}{}_{(aq)}$.

Acidity of $NH_4OH$ is 1, since it produces one hydroxyl ion in its aqueous solution.

$NH_4OH_{(aq)} \rightarrow NH_4^+{}_{(aq)} + OH^{1-}{}_{(aq)}$.

Acidity of $Mg(OH)_2$ is2. Because it can produce two hydroxyl ion in its aqueous solutions $Mg(OH)_{2\,(aq)} \rightarrow Mg_4^{+2}{}_{(aq)} + 2\ OH^{1-}{}_{(aq)}$.

**4.6 SALT**: Thesubstance which is produceby the neutralization reaction along with water. Acid reacts with base to produce salt and water; such reaction is called neutralization reaction. On evaporation of water substance left behind is salt.Common examples of salts areNaCI, KCI, $K_2SO_4$, AgCl etc.

Table 4.1: Examples of neutralization reactions

| No | Acid | + Base→ | Salt | + | Water |
|---|---|---|---|---|---|
| 1 | $HCl_{(aq)}$ | + $NaOH_{(aq)}$→ | $NaCl_{(aq)}$ | | + $H_2O_{(l)}$ |
| 2 | $H_2SO_{4\,(aq)}$ | + $NH_4OH_{(aq)}$→ | $(NH_4)_2SO_{4(aq)}$ | | + $H_2O_{(l)}$ |
| 3 | $CH_3COOH_{(aq)}$ | + $NH_4OH_{(aq)}$→ | $CH_3COONH_{4(aq)}$ | | + $H_2O_{(l)}$ |

**4.7 CONCENTRATION OF SOLUTION:**The amount of solute in given solvent or solution is called concentration of solution.

**4.8 METHODS TO EXPRESS CONCENTRATION OF SOLUTION:**There are different modes of expressing of solution.Some of these are

**4.8.1 Strength**:The mass of solute in gram present in one liter (or per liter) of solution is called strength of solution. The unit of strength of solution isgrams per liter and is represented as ‘g/L.

Mathematically, Let ‘m’ grams of solute present in V liter of solution.

$$\left.\begin{array}{c}\text{Strength of}\\ \text{solution}\end{array}\right\} = \frac{\text{mass of solute in gram}}{\text{volume of solution in liter}} = \frac{m}{V} \text{ g/L.......(1)}$$

If 'v' is volume of solution in milliliter (mL) then, V L = (v mL /1000)L.

Now,

$$\left.\begin{array}{c}\text{Strength of}\\ \text{solution}\end{array}\right\} = \frac{\text{mass of solute in gram}}{\text{volume of solution in liter}} = \frac{m \times 1000}{v} \text{ g/L....(2)}$$

**4.8.2** **<u>Molarity</u>**:The number of moles of the solute present in one liter or per liter of solution is called molarity. It is represented as 'M' ormol/L.

1 molarity = 1M = 1 mole per liter = 1mol/L.

Mathematically,

Let 'm' grams of solute and GM gram molecular mass, present in V liter of solution. Where, GM = gram molar mass of solute expressed in grams per mole (g/mol).

If 'v' is volume of solution in milliliter (mL) then, V L = (v mL /1000)L.

Now,

$$\left.\begin{array}{c}\text{Molarity of}\\ \text{solution}\end{array}\right\} = \frac{\text{mass of solute in gram}}{\text{solute gram molar mass x volume of solution in liter}} \text{ mol/L..(1)}$$

$$\text{Molarity of solution} \left.\right\} = \frac{m}{GM \times V} \text{ mol/L.........(2)}$$

$$\left.\begin{array}{c}\text{Molarity of}\\ \text{solution}\end{array}\right\} = \frac{m \times 1000}{GM \times v\ (mL)} \text{ mol/L...(3)}$$

If, $M_1$ and $V_1$ are molarity and volume of $1^{st}$solution ofhigher molarity respectively, and $M_2$ and $V_2$ are molarity and volume of $2^{nd}$ solution of low molarity respectively.Then, $M_1 V_1 = M_2 V_2$, is called molarity equation.

**4.8.3Normality**:The number of gram equivalent of the solute present in one liter of solution is called normality of solution. It is represented as 'N'

Normality equation is$N_1V_1=N_2V_2$

(Details are beyond the scope of syllabus)

**4.8.4 Simple numerical based on (a) strength and (b) molarity of solution:**

**Problem 1:**Calculate strength and molarity of the 500 mL of NaOH solution containing 2.0 grams NaOH. (Given, gram atomic mass (A) of Na=23,O=16, and H=1 g/mol).

**Solution**: Given,m = mass of NaOH solute= 2.0 gNaOH,

Volume of NaOH solution in mL = 500mL.

Now,GM =gram molar mass of NaOHsolute= (1x23+ 1x16+1x1) =40 g/mol NaOH.

Substituting these values in the strength equation (2) to calculate strength:

$$\left.\begin{array}{c}\text{Strength}\\ \text{of NaOH}\\ \text{solution}\end{array}\right\} = \frac{m \times 1000}{v} = \frac{2 \times 1000}{500}\ g/L\ \frac{2 \times 1000}{500}\ g/L = 4\ g/L$$

Substituting these values in the molarity equation (3) to calculate molarity

$$\left.\begin{array}{c}\text{Molarity of NaOH}\\ \text{solution}\end{array}\right\} = \frac{m \times 1000}{GM \times v\,(mL)}\ mol/L$$

$$\left.\begin{array}{c}\text{Molarity of}\\ \text{NaOH solution}\end{array}\right\} = \frac{2 \times 1000}{40 \times 500}\ mol/L = 0.1\ M\ NaOH$$

**Problem 2:** Find the strength and molarity of the 2 liter of $H_2SO_4$solution prepared by dissolving 49 g $H_2SO_4$. (Given gram atomic masses (A) of H=1, S=32, O=16)

**Solution**: m = mass of $H_2SO_4$solute= 49 g$H_2SO_4$,

Volume of $H_2SO_4$solution in liters =2L,

GM = Gram molar mass of $H_2SO_4$solute= 1x2+32+16x4=98 g/mol $H_2SO_4$.

Substituting these values in the strength equation (1) to calculate strength:

$$\left.\begin{array}{c}\text{Strength}\\ \text{of } H_2SO_4 \text{solution}\end{array}\right\} = \frac{m}{V} = \frac{49}{2}\ g/L = 24.5\ g/L\ H_2SO_4$$

Substituting these values in the molarity equation (2) to calculate molarity

$$\left.\begin{array}{c}\text{Molarity of}\\ H_2SO_4 \text{solution}\end{array}\right\} = \frac{m}{GM \times V}\ mol/L$$

$$\left.\begin{array}{c}\text{Molarity of}\\ H_2SO_4 \text{solution}\end{array}\right\} = \frac{49}{98 \times 2}\ mol/L = 0.25\ M\ H_2SO_4$$

**4.9 DEFINITION OF pH:** The negative logarithm of molar concentration of hydrogen ion ($H^+$) orhydronium ion ($H_3O^+$) present in solution is called pH of solution.

Mathematically,pH= - log $[H^+]$ or

pH= - log $[H_3O^+]$,

pH is measured by using 1) pH meter 2) pH paper

**4.9.1 Industrial application of pH**: pH has large number of industrial applications; some of them are listed here

1) pH give information about nature of solution, i.e. acidic, basic, or neutral.

pH values

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |

←Acidic strength increase ← neutral →Basic strength increases →

If pH of solution is between 0 and >7 solution will be acidic in nature.If pH of solution lays < 7 to 14, such solution will be basic in nature.If pH of solution = 7 it will be neutral solution.

2) In acid-base titration pH is used to detect end point.
3) pH play important roles crystallization of sugar in sugar industries.
4) pH play important roles in preparation of drugs in pharmaceutical industries.
5) pH play important roles in metabolism of food.
6) In food industries, food preservation also needs a definite pH.
7) pH also play important role in agriculture, soil is often tested whether acidic or basic fertilizers are required for growth of crops.
8) The control of pH is also required in boiler industries because acidic pH cause corrosion to boiler.
9) In electroplating, electrolytic machining (honing) process pH of electrolytes play important role.
10) Corrosion preventive measures of instrument or machines are developed with respect to prevailing pH value under service conditions of such instrument or machines.

**Questions for Revision:**

1. On mixing two or more chemical substances can form only form solution, if it is a _______ mixture?

a) heterogeneous  b) homogeneous  c) mixture  d) reacting

2. Substance in a solution, in which solute dissolve is called____

a) solution  b) solvent  c) solute  d) mixture

3. Substance in a solution, which get dissolve is said to be ____

a) solution  b) solvent  c) solute  d) mixture

4. Concentration of solution is influenced by

a) pressure  b) solvent quantity  c) both b & d  d) temperature

5. Numbers of replaceable hydrogen ion of an acid, hydroxyl ion of a base are ____ & ____ respectively.

a) basicity & acidity  b) acidity & basicity  c) both a & b  d) none

6. Unit of strength is

a) mol/L  b) g / L  c) mol / kg  d) ppm

7. Unit of molarity

a) ppm  b) g / L  c) mol / L  d) mol / kg

8. Molarity of resulting solution prepared by diluting higher molar concentration solution to lower molar solution can be calculate using equation:

a) $M_1 V_1 = M_2 V_2$ b) $N_1 V_1 = N_2 V_2$ c) $M_1 V_1 > M_2 V_2$ d) $M_1 V_1 < M_2 V_2$

9. Hydrogen ion concentration of the given solution can be expressed as $P^H$ =

a) log $[H^+]$ b) log $(1/[H^+])$ c) - log $[H^+]$ d) both (b) or (c)

10. $P^H$ the given solution can be play important role in_______ industries

a) beverage b) paper c) lather d) all

**Short answer questions**

1) What is the acidity of $Mg(OH)_2$?
2) Define solution.
3) What do you mean by solute and solvent?
4) Define binary solution.
5) Mention the $P^H$ of water.
6) Give the $P^H$range of acidic solution.
7) What is the $P^H$range of basic solution?
8) What is the basicity of sulfuric acid?
9) What is the SI unit of molarity?
10) What is the pH for pure water?
11) Define strength of solution.

**Long answer questions**

12) Define the following with help of suitable examples
    i) Acidity ii) Basicity
13) Define the following terms
    i) Strength ii) Molarity iii) Acid iv)Base
14) What is pH? Give its mathematical expression.
15) Discuss its industrial applications.
16) Write the molarity equation.
17) Calculate the Molecular weight of following
    i) $CH_3COOH$ ii) $H_2SO_4$ (Use atomic mass (A g/mol) of C=12,S=32,O=16, H=1)
18) A solution is prepared by dissolving 29g $Mg(OH)_2$in 250 mL solution.Calculate its strength and molarity. (Use atomic mass (A g/mol) of Mg=24, O=16,H=1).
19) $CaCl_2$2L solution,is prepared by dissolving 11.1g $CaCl_2$.Calculate strength and molarity of $CaCl_2$solution. (Use atomic mass (A g/mol) of Ca=40, Cl=35.5).
20) What is solution? Explain solute and solvent using suitable example.
21) What is binary solution? Give examples.
22) Identify mixture and solution from the followings:
    a) Soil
    b) Air
    c) Sea water

d) Crude oil

23) How temperature is influences strength and molarity of solution?

24) Calculate the molarity of 250mL sulfuric acid solution obtained by diluting 25 mL of 1M sulfuric acid.

25) How are molarity and strength of solution related? Write the equation.

26) Mention the methods to express the concentration of

a) Polluted water

b) Air pollution

27) Two liters of solution of $H_2SO_4$is prepared by dissolving 5 grams$H_2SO_4$, calculate molarity of sulfuric acid.

28) Two liters of NaOH solution is prepared by dissolving 5 grams NaOH, calculate molarity of sodium hydroxide solution.

29) How are strength and molarity of these solutions related?

**Answers to objective type questions:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | b | 2. | b | 3. | c | 4. | c | 5. | a |
| 6. | b | 7. | c | 8. | a | 9. | d | 10. | d |

# UNIT - 5

## ELECTROCHEMISTRY

**Learning Objectives:** By learning this unit students will be able to:

- understand electronic concepts of oxidation and reduction and redox reactions.
- classify the substance based on electric conductance into electrolytes, non-electrolytes
- distinguish metallic conductors and electrolytic conductors, and strong and weak electrolytes
- understand Faraday's laws of electrolysis and its industrial applications
- understand chemistry and technology involved in the industrial extraction of metals.

**5.1 ELECTROCHEMISTRY AND ITS IMPORTANCE:**Electrochemistry is that branch of chemistry which primarily deals with the relation between chemical energy and electrical energy and their inter conversions. The principles of electrochemistry help us to understand production of electricity from energy released during chemical reactions and the use of electrical energy to carry out chemical reactions.

**Importance of Electrochemistry:**

1 Extraction of more electropositive metals like Na, Mg. Ca and Al.
2 Electroplating, Electrolytic refining, Electrometallurgy.
3 Electrochemical cells and batteries and used in various instruments.
4 Understand corrosion of metals and develop preventive techniques.
5 Production of fuel cells.

**5.2 ELECTRONIC CONCEPT OF OXIDATION AND REDUCTION:**After establishment of atomic structure the electronic concept of oxidation and reduction is developed.

**5.2.1 Oxidation:**The oxidationis a process in which a substance looses one or more electrons. Consider the following examples:

| | |
|---|---|
| $Na_{(s)} \rightarrow Na^{+1}_{(g)} + 1\ e^{-1}$} | Sodium metal atom loose an electron, hence it is said to be oxidized to form sodium cation. |
| $Fe^{+2}_{(aq)} \rightarrow Fe^{+3}_{(aq)} + 1\ e^{-1}$} | Ferrous ion undergoes oxidation by the loss of an electron to form ferric ion. |

Therefore, loss of electrons by a species is called oxidation. Here, species means it may be an atom or group of atoms or ion or a molecule.

**5.2.2 Reduction:**The reduction is a process in which a substance gains one or more electrons. Consider the following examples:

| | |
|---|---|
| $Na^{+1}_{(g)} + 1\ e^{-1} \rightarrow Na_{(s)}$} | Sodium cation gains an electron, hence it is said to be oxidized to form sodium metal atom. Thus, sodium metal is manufactured by the electrolytic reduction of molten sodium chloride. |

| | |
|---|---|
| $Fe^{+3}_{(l)} + 3\ e^{-1} \rightarrow Fe_{(s)}\}$ | Ferric ion undergoes reduction by the gaining an electron to give iron. Thus, heamatite ore is reduced to iron using coke in the blast furnace. |
| $Cu^{+2}_{(aq)} + 2\ e^{-1} \rightarrow Cu_{(s)}\}$ | Cupric ion gains two electrons hence undergo reduction to form copper. It is used in construction of Daniel cell. |

Therefore, gain of electrons by a species is called reduction.

**5.2.3 Redox reaction:** Oxidation and reduction take place simultaneously. Therefore, redox reaction is a process in which oxidation and reduction take place simultaneously. Let us consider the following reaction to understand oxidation, reduction, reducing agent and oxidizing agent.

| | |
|---|---|
| $4\ Fe_{(s)} \rightarrow 4Fe^{+3} + 12\ e^{-1}\}$ | 1. Iron oxidized to form ferric ion. |
| $3\ O_{2(g)} + 12e^{-1} \rightarrow 6\ O^{-2}_{(g)}\}$ | 2. Oxygen undergoes reduction to give oxide iron. |
| $4\ Fe_{(s)} + 3\ O_{2(g)} \rightarrow 2Fe_2O_{3\ (s)}\}$ | 3. Ferric ion combines with oxide ion to form ferric oxide. (adding equation 1 and 2) |

It is now clear that iron undergoes oxidation due to loss electrons, and oxygen undergoes reduction due to gain of electrons, finally ferric oxide is formed. Therefore, ferric oxide formation reaction is a redox reaction. Since it involves oxidation of iron and reduction of oxygen simultaneously. What is the action of iron on oxygen and vice versa? In above redox reaction iron can undergo oxidation only when oxygen undergoes reduction. Thus, iron force the oxygen to undergo reduction hence, iron is a reducing agent. On the other hand oxygen force the iron to undergo oxidation hence, it is oxidizing agent.

Table 5.1: Summary

| | |
|---|---|
| Oxidation is loss of electrons by a species. | A species which undergoes oxidation will act as reducing agent. |
| Reduction is gain of electrons by a species. | A species which undergoes reduction will act as oxidizing agent. |

## 5.3 CONDUCTORS:
**5.3 CONDUCTORS:** Substances that allow electric current to pass through them are known as conductors. Examples of conductors aremetals like copper, silver, iron, zinc and aqueous solution of NaCl, KCl, HCletc.

**5.3.1 Metallic Conductors or Electronic Conductors**Substances which allow the electric current to pass through them by the movement of electrons are called metallic conductors, e.g.Metals like copper, iron, aluminum, silver, gold etc.

**5.3.2 Electrolytic Conductors or Electrolytes**:Substances which allow the passage of electricity through their molten (fused) state or aqueous solution are called electrolytic conductors.In aqueous solution or molten state of electrolytes contain, ions. The migration of these ions help an electrolyte to conduct electricity, hence are called electrolytic conductors. e.g., aqueous solutionof acids like HCl, $H_2SO_4$,

$HNO_3$, $CH_3COOH$, bases like KOH, NaOH,$NH_4OH$ and salts like NaCl, KCl, $K_2SO_4$etc.

The spontaneous splitting up of an electrolyte into ions in its molten or aqueous solution state is called ionization or dissociation. Examples for ionization are

1. $HCl_{(g)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^{-1}_{(aq)}$
2. $H_2SO_{4(aq)} \rightarrow 2\ H^+_{(aq)} + SO_4^{-2}{}_{(aq)}$
3. $KCl_{(aq)} \rightarrow K^+_{(aq)} + Cl^{-1}_{(aq)}$
4. $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^{-1}_{(aq)}$
5. $CH_3COOH_{(aq)} \rightarrow H^+_{(aq)} + CH_3COO^{-1}_{(aq)}$

## 5.4 TYPES OF ELECTROLYTES:

Electrolytes are of two types:

**5.4.1 Strong electrolytes**: The electrolyteswhich dissociate or ionize completely into ions in either molten or aqueous state are called strong electrolytes. e.g., HCl, $H_2SO_4$, $HNO_3$, KOH, NaOH, NaCl, KCl, $K_2SO_4$ etc.

Table 5.2: Illustrative examples of strong electrolytes

| | |
|---|---|
| 1. $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^{-1}_{(aq)}$<br>If $[HCl_{(aq)}]$=0.1M<br>Then, $[H^+_{(aq)}]$ = 0.1M and $[Cl^{-1}_{(aq)}]$ = 0.1M. | Thus, $HCl_{(aq)}$ is complete dissociatedin aqueous solution state. Hence HCl is strong electrolyte. |
| 2. $KCl_{(aq)} \rightarrow K^+_{(aq)} + Cl^{-1}_{(aq)}$<br>If $[KCl_{(aq)}]$=0.01M<br>Then,$[K^+_{(aq)}]$ = 0.01M and$[Cl^{-1}_{(aq)}]$= 0.01M | Thus, $KCl_{(aq)}$ is complete dissociatedin aqueous solution state. Hence KCl is strong electrolyte. |

**5.4.2 Weak electrolytes:** The electrolytes which dissociate into ions partially in their aqueous or molten state are called weak electrolytes, e.g., $CH_3COOH$, $H_2CO_3$, $NH_4OH$, AgCl etc.

Table 5.3: Illustrative examples of weak electrolytes

| | |
|---|---|
| 1. $NH_4OH_{(aq)} \rightarrow NH_4^+{}_{(aq)} + OH^{-1}_{(aq)}$<br>If $[NH_4OH_{(aq)}]$=0.1M<br>Then, $[NH_4^+{}_{(aq)}] < 0.1M$ and<br>$[OH^{-1}_{(aq)}] < 0.1M$. | Thus, $NH_4OH_{(aq)}$ is partially dissociatedin aqueous solution state. Hence $NH_4OH_{(aq)}$ is weak electrolyte. |

**5.5 ELECTROLYSIS:**The process of decomposition of an electrolyte when electric current is passed through either its aqueous solution or molten state is called electrolysis.

**5.6 NON- ELECTROLYTE:**Substance which does not allow electricity to pass through either in its fused (molten) state or aqueous solution stateis called non-electrolyte. Some example of non- electrolyte are urea, sugar, glucose etc.

## 5.7 FARADAYS LAWS OF ELECTROLYSIS:

**5.7.1 Faraday's first law of electrolysis:** According to Faraday's first law of electrolysis, "The amount of the substance deposited or liberated at electrodesis directly proportional to thequantity of electricity passed through electrolyte."

Mathematically,if

'W' is the mass of substance deposited or liberated at electrode.

Then,

$$W \propto I \text{ x } t \text{or}$$
$$W = I \text{ x } t \text{ x } Z \text{or}$$
$$W = Q \text{ x } Z, \text{ where } Q = It$$

Here, I= current in ampere (A), t = time in second (s), Q = quantity of charge in coulomb (C). Z is a constant known as electrochemical equivalent of substance grams per coulomb (g/C).Q = It

When I = 1 A, t = 1 sor Q = 1 C, then, W= Z.

Thus, electrochemical equivalent of the substance is the amount of the substance deposited or liberated on electrode, when 1A current is passedthrough its electrolytic solutionfor 1s.

Quantity of electric charge (Q) = (I x t) C = (1) As.

**5.7.2 Faraday's second law of electrolysis:**According to Faraday's second law of electrolysis, "The amount of the substances deposited or liberated at the electrodes by passing the same quantity of electricity through solutions of different electrolytes is directly proportional to their equivalent weights or their electrochemical equivalents.Thus,

$$\frac{\text{Mass of A}}{\text{Mass of B}} = \frac{\text{Equivalent weight of A}}{\text{Equivalent weight of B}}$$

$$\frac{W_1}{W_2} = \frac{E_1}{E_2} \Rightarrow \frac{z_1 Q}{z_2 Q} = \frac{E_1}{E_2}$$

Hence, electrochemical equivalent ∝ equivalent weight

**Michael Faraday:** Born on 22nd September 1791 near London village. He had his elementary education while working as newspaper boy. He was affectionate by Sir H. Davy and worked as his scientific assistant. Faradays contribution to the science is remarkable. Electromagnetic induction, dynamo effect, laws of electrolysis, magnetism and Faradays effect, gravity and magnetism, magnetic field influence on spectrum of sodium, preparation of steel, composition of clay, lime, water, gun powder rust, various gases, discovery of benzene, production glass, liquefaction of gases, adsorption, plasma chemistry, dielectric constant, and colloidal metals. (Source book is Understanding Chemistry by C. N. R. Rao).

**5.8 ELECTROCHEMICAL CELL:** A device which converts efficiently chemical energy of a redox reaction into electric energy.

**Batteries:**Two or more than two cells connected in series are known as battery.For a good quality battery it should be reasonably light,compact and its voltage should not vary appreciably during its use.

**5.9 INDUSTRIAL APPLICATION OF ELECTROLYSIS:** Some important application of electrolysis are:

**5.9.1 Electrolytic refining**: The process of purification of metals (crude or impure metal) by electrolysis method is called electrolytic refining. The metals like Copper and aluminum are refined (purified) by using electrolytic refining.

**Method**

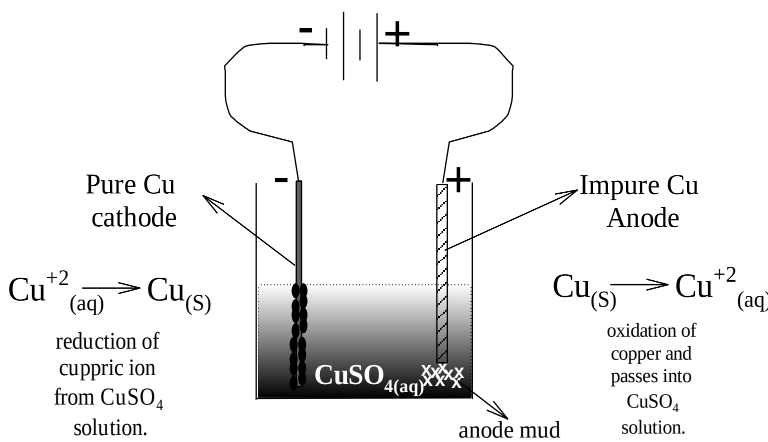



Fig 5.1 Electrolytic refining of copper

The metal (say impure Cu) which is to be purified is connected with positive terminal of battery, which act as anode. The pure rod of same metal (say pure Cu) is connected with negative terminal of battery, which act as cathode. The solution of salt of same metal (say $CuSO_4$) acts as electrolyte. On passing current (electricity) the impure metal (anode) dissolve and pass into solution in the form of ions and same number of ions from solution deposit on cathode in the form of pure metal. More reactive metalimpurities are passes into the solution. Other the impurities of less reactive metals settle below anode in the form of anode mud or anode sludge.

**The process is shown by reaction below**

**Anode:** Cu (impure) $\rightarrow$ $Cu^{2+}$ + 2 $e^-$**Cathode:** $Cu^{2+}$ + 2 $e^-$$\rightarrow$ Cu (pure)

**5.9.2 Electrometallurgy:**The process of extraction of highly electropositive metals by electrolysis of their fused oreis called electrometallurgy.The more reactive metals like alkali metals (Li, Na, K), alkaline earth metals(Mg, Ca,Sr) and Aluminum (Al) are extracted from their ore by principles of electrometallurgy.

Extraction of sodium from fused sodium chloride:Sodium is extracted from fused (molten) sodium chloride by electrolysis electrode reactions are as given below:

$\mathbf{NaCl}_{(Molten)} \rightarrow \mathbf{Na^{+}}_{(Molten)} + \mathbf{Cl^{-1}}_{(Molten)}$.

**At Anode:** $2Cl^{-1}_{(Molten)} \rightarrow Cl_{2(g)}$ (Librated) + $2e^{-}$

**At cathode**: $2\ \mathbf{Na^{+}}_{(Molten)} + 2e^{-} \rightarrow 2\ Na_{(s)}$ (Deposited)

**5.9.3 Electroplating:** The process of coating a layer of superior metal on inferior metals surface by electrolysis is called electroplating.The electroplating is done

1 To protect the metal or alloy from corrosion.
2 To improve the surface and provide aesthetic look to metal.

**Method:**

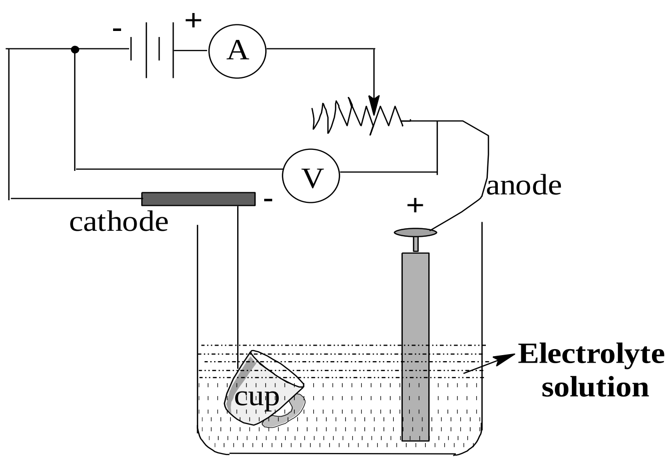



Fig 5.2. Electroplating

The metal (say Fe) which is to be electroplated or inferior metal is connected to negative terminal of battery, which act as cathode. The rod of superior metal (say Zn) is connected to positive terminal of battery, which act as anode. The solution of salt of pure metal (say $ZnSO_4$) acts as electrolyte. On passing current (electricity) the superior metal (anode) dissolve and pass into solution in the form of ions and same number of ions from solution deposit on cathode.

The electrode reactions are given below

**Anode:** $Zn \rightarrow Zn^{2+} + 2e^{-}$ and **Cathode:** $Zn^{2+} + 2e^{-} \rightarrow Zn$

**Questions for Revision**

1. Any species which loose electrons is said to be undergoing___________

a) reduction b) oxidation c) redoxed d) combination

2. Any species which gain electrons is said to be undergoing___________

a) reduction b) oxidation c) redoxed d) combination

3. Substance in its molten or aqueous solution state conducts electricity is called ________

a) metallic conductor b) electrolytic conductor c) semi conductor d) all

4. Chemical substance which undergoes partial ionization in its aqueous or molten state is _____.

a) strong electrolyte b) non electrolyte c) weak electrolyte d) metal

5. Chemical substance which undergoes complete ionization in its aqueous or molten state is ______.

a) strong electrolyte b) non electrolyte c) weak electrolyte d) metal

6. Spontaneous splitting up of an electrolyte into its ions in its molten or aqueous state said to be ___________.

a) ionization b) melting c) association d) none

7. Process of spontaneous splitting up of chemical substance by the passage electric current is called ___________

a) association b) melting c) electrolysis d) all

8. In electrolytic cell the electrode at which oxidation take place is _________.

a) anode b) cathode c) electrolyte d) neutral

9. Electrode at which reduction take place, in electrolytic cell is called________.

a) anode b) electrolyte c) cathode d) neutral

10. W = I x t x Z is the mathematical expression of Faradays, ______ law of electrolysis.

a) $1^{st}$ b) $2^{nd}$ c) $0^{th}$ d) none

11. W = I x t x Z is the mathematical expression of Faradays law of electrolysis. Where units of W, I and t are respectively ________, ________ & ________.

a) g, A & minutes b) g, A & s c) kg, V, & s d) none

12. The amount of the substances deposited or liberated at the electrodes by passing the same quantity of electricity through solutions of different electrolytes is directly proportional to their equivalent weights or their electrochemical equivalents. It is Faradays, ______ law of electrolysis.

a) $1^{st}$ b) $2^{nd}$ c) $0^{th}$ d) none

13. Battery in the mobile is an example of _________ cell.

a) electrolytic b) bio c) electrochemical d) all

14. Battery of a mobile, while recharging will act as ________ cell.

a) electrolytic b) bio c) electrochemical d) all

15. The cell used to manufacture sodium by the electrolysis of molten sodium chloride, know as ________ cell.

a) electrochemical b) battery c) fuel cell d) electrolytic

**Short answer questions**

1. What is oxidation?
2. What is reduction?
3. Define redox reaction.
4. Can oxidation or reduction take place independently?
5. What are electrolytes?
6. Why crystalline solid sodium chloride does not conducts electric current?
7. What is weak electrolyte? Give an example.
8. What is a strong electrolyte? Give an example.
9. What is reason only aqueous or molten electrolyte can conducts electric current?

**Long answer questions**

10. What is ionization of electrolyte? Explain.
11. Explain redox reaction with suitable example.
12. Give two examples of electrolytic conductors.
13. How are electrolytes classified? Explain each type with suitable example.
14. Differentiate between oxidation and reduction.
15. Why crystalline solid sodium chloride does not conducts electric current?
16. Differentiates between conductors and non-conductors.
17. Differentiate between electrolyte and non electrolyte.
18. Differentiate between strong electrolyte and weak electrolyte.
19. State and explain Faradays 1$^{st}$ law of electrolysis.
20. Define Faradays 2$^{nd}$ law of electrolysis. Give its mathematical derivation.
21. Write a short note on electrolytic refining.
22. Differentiate ionization and electrolysis.
23. Explain the process of electro refining.
24. Explain different industrial application of electrolysis:
    a) Electrolytic refining
    b) Electrometallurgy
    c) Electroplating.
25. What is electroplating? Explain with diagram.
26. What is an electrochemical cell?

27. What are batteries?
28. How metallic conductors differ from electrolytic conductors? Explain.
29. What is mobile battery called, while it is recharging?
30. Mention natural redox reactions examples from daily life.
31. Write electrode reactions for the following processes
    a) Electrolysis of molten sodium chloride.
    b) Electrolytic refining of impure copper.

**Answers to objective type questions:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | b | 2. | a | 3. | b | 4. | b | 5. | a |
| 6. | a | 7. | c | 8. | a | 9. | c | 10. | a |
| 11. | b | 12. | b | 13. | c | 14. | a | 15. | d |

# UNIT - 6

## GENERAL PRINCIPLES OF EXTRACTION OF METALS

**Learning Objectives:** By learning this unit students will be able to:

- understand general terminology in metallurgy, and steps involved in metal extraction.
- recognize minerals and ores of various metal.
- define alloys, purpose of alloying and classification of alloys
- understand chemistry and technology involved in the industrial extraction of metals.

### 6.1 METALS AND NON-METALS:

**Metals:**The elements which are hard, dense, malleable, ductile, good conductor of electricity, electropositive in character and have bright luster and having high melting and boiling point are called metals. Examples are copper, silver, iron, aluminum etc.

**Non-Metals:**The elements which are generally not malleable, not ductile, bad conductor of electricity, electronegative in character are called non- metals. Examples are hydrogen, oxygen, carbon, sulfur etc.

**6.2 MINERA**L:The natural substance in which metal occur either in native state or in the combined state is called mineral.

**6.2.1 Ore:**The mineral from which the metal can be extracted easily and economical is called ore. e.g

**Hematite ($Fe_2O_3.xH_2O$)** is ore of iron.

**Bauxite ($AI_2O_3.2H_2O$)** is the ore of aluminum

**Copper pyrite ($CuFeS_2$)** is the ore of copper

**6.3 DEFINITION OF METALLURGY:**The extraction of metals from their chief ore is called metallurgy.

**6.3.1 Types of metallurgy:**

Metallurgy is of three types:

a) Pyrometallurgy**:** Extraction of metals from their ore by heating with coke (carbon) or Carbon monoxide is called pyro-metallurgy. Iron (Fe) is extracted fromHematite ($Fe_2O_3.xH_2O$)by heating with coke.
b) Electrometallurgy:Extraction of metals from their ore by the process of electrolysis is called electrometallurgy. Aluminum is extracted from fused alumina mixed with cryolite by electrometallurgy.
c) Hydrometallurgy: The extraction of metal from their ore by dissolving insuitable solvent then precipitating the metal from the solution by more reactive metal is

called hydrometallurgy. Au (gold) and Silver (Ag) are extracted from their ore by hydrometallurgy.

## 6.4 GENERAL STEPS OF METALLURGY:

a) **Crushing of ore**: The process of converting big piece (lumps) of ore into smaller pieces is called Crushing of ore. It is done with the help of jaw crusher

b) **Pulverization of ore**: The process of converting crushed ore into powder form is called pulverization of ore. This process is carried with the help of ball mill or stamp mill.

c) **Concentration of ore/ benefaction process:**The process of removing impurities from pulverized ore is called concentration of ore.Depending on the nature of ore and impurities the following methods are used for concentration of ore

**Gangue or matrix**

The siliceous and earthy impurities of associated with ore is called gangue/ matrix.

**Flux**

The substance which is added in the ore to remove gangue (impurities) during reduction is called flux. It is of two types: Acidic flux: $SiO_2$, Basic flux: CaO, FeO, MgO

**Slag**

The fusible mass formed by combination of flux and gangue is called slag.

$CaO + SiO_2 \rightarrow CaSiO_3$

Flux Gangue Slag

i) **Gravity separationii) Froth floatation process**

i) **Gravity separation method:**This method is used for concentration of oxide and carbonate ore.

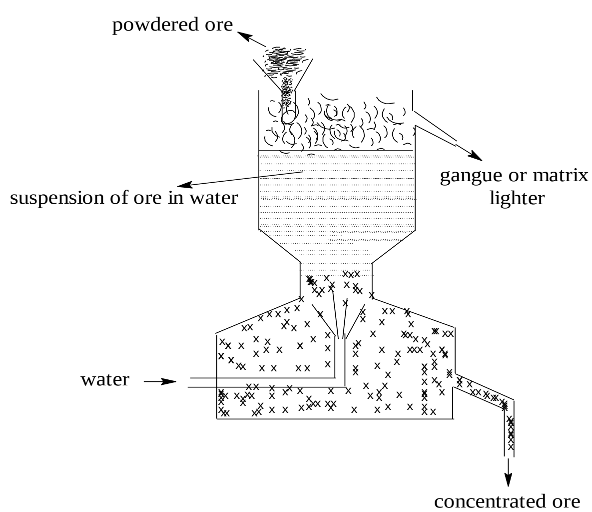



Fig 6.1 Hydraulic washing

It is based on the fact that ore particles are heavier than gangue. The pulverized ore is taken in a tank, stream of water enter in the tank at one end and leaves at other. The lighter gangue particles are carried by water where as heavy ore particles settle at the bottom of the tank. Thus ore get concentrated.  e. g., Heamatite ($Fe_2O_3.xH_2O$) an   ore of iron is concentrated by this method.

ii) **Froth floatation process:** This process is generally used for concentration of sulfide ore like copper pyrite ($CuFeS_2$).

**Principle of froth floatation process:** It is based on the principle that oreparticles are preferentially wetted by oil while the impurities arepreferentially wetted by water.

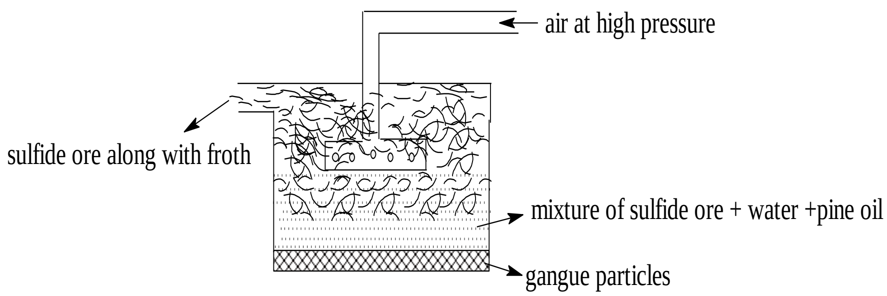



Fig 6.2 Froth floatation process for concentration of sulfide ores

In this method the pulverized ore is put in a tankcontaining mixture of water and pine oil. The air is drawn in thetank with perforated pipe. The oil form froth with air.Thesulfide ore particles wetted by oil stick to froth;become lighterand rise to the surface whereas impurities wetted by water become heavy and settle down at the bottom of tank. The froth carrying the ore particles overflow into the settling tank where the ore settle down after sometime and get concentrated.

**d) Oxidation of ore:** The process of converting non oxide ore into oxide form is called oxidation of ore. Depending on the nature of ore the following methods are used for oxidation of ore**.**i) Roasting ii) Calcination

**i)** **Roasting**:The process of heating concentrated ore in the excess of airbelow its melting point is called roasting.Roasting is carried out for the oxidation of sulfide ore like copper pyrite to oxide ore.The process of roasting and calcinations (oxidation of ore) carried outin Reverberatory Furnace.During roasting the sulfide ore changes into oxide ore

$ZnS + 3O_2 \rightarrow 2ZnO + 3SO_2$

**ii)** **Calcination**: The process of heating concentrated ore either in limited supply of air or in the absence of air below itsmelting point is called calcinations.**Calcination** is the process of oxidation of **oxide or carbonate ore like Heamatite ($Fe_2O_3.xH_2O$), an ore of Iron.**The process of roasting and calcinations (oxidation ofore) is carried out in **Reverberatory Furnace** During calcination the Carbonate ore changes into oxide ore

$ZnCO_3 \rightarrow ZnO + CO_2$

**e) Reduction:** The process of obtaining metal from roasted or calcinated oreis called reduction. Depending on nature of metal and oredifferent methods of reductions are used. These are i) Smelting ii) Electrolytic reduction

**i) Smelting:** The process of extraction of metal from its ore by heating itwith coke or CO at its melting point is called smelting. e.g. Ironis extracted from Heamatite ($Fe_2O_3.xH_2O$) by heating with Coke

**ii) Electrolytic Reduction:** The process of obtaining metal by passing electricity from molten state of its ore is called electrolyticreduction. The more reactive metal like aluminum, alkali metals (Li,Na,K ) and alkaline earth metals(Mg,Ca) are obtained from their ore by electrolytic reduction. Or Extraction of metals from their ore by the process of electrolysis is calledelectrolytic reduction. The more reactive metal like aluminum, alkali metals (Li,Na,K ) and alkaline earth metals(Mg,Ca) are obtained from their ore by electrolytic reduction.

Extraction of sodium from sodium chloride: Sodium is extracted from fused (molten) sodium chloride by electrolysis electrode reactions are as given below:

$NaCl_{(Molten)} \rightarrow Na^{+}_{(Molten)} + Cl^{-1}_{(Molten)}$.

At Anode: $2\,Cl^{--1}_{(Molten)} \rightarrow Cl_{2(g)}$ (Librated) $+ 2e^{-}$

At cathode: $2\,Na^{+}_{(Molten)} + 2e^{-} \rightarrow 2\,Na_{(s)}$ (Deposited)

**f) Refining of metal:***The process of removing impurities from crude (impure) metal iscalled refining of metal.* There are different methods of refining of metaldepending on. Some of them are nature of metal and impurities. Some of them are

1. Electrolytic refining
2. Mond Process

Electrolytic refining:The process of purification of metals (crude or impure metal) byusing electrolysis is called electro- refining.The metals like Copper and aluminum are refined (purified) by sing electrolytic refining.

**Method**

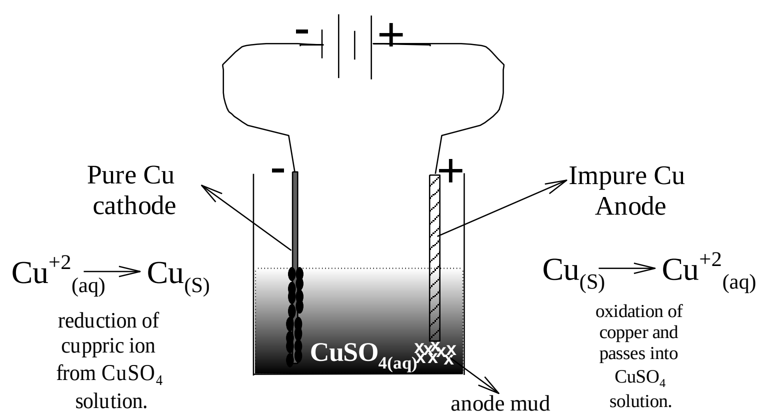



Fig 6.3 Electrolytic refining of copper

The metal (say impure Cu) which is to be purified is connected with positive terminal of battery, which act as anode. The pure rod of same metal (say pure Cu) is connected with negative terminal of battery, which act as cathode. The solution of salt of same metal (say $CuSO_4$) acts as electrolyte. On passing current (electricity) the impure metal (anode) dissolve and pass into solution in the form of ions and same number of ions from solution deposit on cathode in the form of pure metal. More reactive metalimpurities are passes into the solution. Other the impurities of less reactive metals settle below anode in the form of anode mud or anode sludge.

**The process is shown by reaction below**

**Anode:** Cu (impure) $\rightarrow$ $Cu^{2+}$ + 2 $e^-$**Cathode:** $Cu^{2+}$ + 2 $e^-$$\rightarrow$ Cu (pure)

## 6.5 DEFINITION OF ALLOY:

**6.5 DEFINITION OF ALLOY:** An alloy is homogeneous mixture of two or more metals or metals and non- metals. e.g., sodium amalgam is an alloy of sodium and mercury.

**6.5.1 Types of alloys:**Alloys are mainly of two types:

1. **Ferrous alloys:** The alloys which contain iron as a main constituent is called ferrous alloys. Example Steel, invar, alnico are ferrous alloys.
2. **Non-ferrous alloys**:The alloys which *not* contain iron as a constituent is callednon-ferrous alloys.Example Brass, bronze and solder, duralumin are non ferrous alloys.

### 6.5.2 Purpose of alloying:

The main purpose of making an alloy is as follows:

1. **To improve the hardness of metal**: Alloys are made to make the metal hard e.g. pure iron is soft and cannot be used as such for machinery part. Thus it is mixed with small quantity of carbon to harden it.
2. **To lower the melting point of metal**: The melting point of an alloy is lower than its constituents. The solder an alloy of lead and tin has lower melting point than both.
3. **To increase the tensile strength**: The alloying is used to increase the tensile strength of metals. Addition of 1% carbon increases the the tensile strength of pure iron by 10 times.
4. **To prevent metal from corrosion**: Alloy is made to prevent metal from corrosion. For example (e.g.) iron can be protected from corrosion by alloying it with Cr ( for making steel)
5. **To modify color**: Alloy is made to modify the color of metal. e.g. Brass, an alloy of copper and Zn has beautiful golden color.

**Questions for Revision**

1. More reactive metals occur in nature in ___________ state

a) free b) combined c) flux d) all

2. Gold, silver and platinum metals occur in nature in _____________

a) combined state b) free state c) mineral d) gangue

3. $Fe_3O_4.x\ H_2O$ is the chemical composition of _______________ ore

a) haematite b) bauxite c) pyrite d) none

4. The only non metal which is good conductor of electric current is

a) mercury b) iron c) diamond d) graphite

5. Brass is ____________ alloy

a) ferrous b) steel c) non ferrous d) mixture

6. Principles of science and technology involved extraction of metal from its chief ore is called___________

a) mineral b) ore c) metallurgy d) all

7. A substance used in smelting process which combines with gangue to form slag is called _________

a) mineral b) ore c) metallurgy d) flux

8. __________metals can only be extracted by the electrolysis of their fused salts.

a) All b) Alkali c) Fe, Al and Cu d) Steel

9. Alloying of metal will

a) Increase corrosion resistance b) Improve melting point c) Appearance d) All

10. Impure metal casted into big block should be used as _____ in electrolytic refining.

a) anode b) cathode c) neutral d) none

**Short answer questions**

11. Extraction of metals by the process of electrolysis is called _____________.
12. ___________process is generally used for concentration of sulfide ore.
13. What is a metal? Give examples.
14. What is non metal? Give examples.
15. How are metal occur in nature?
16. Name the noble metals are found in Free State (native) in nature
17. Define mineral.
18. Define ore.

19. What is matrix or gangue?
20. Define slag.
21. What is Flux?
22. Mention most available metal in the earth's crust.
23. Can air be source of any elements? If so, mention names such elements.
24. Give the name and chemical composition of following metal ores:
    a) Iron
    b) Aluminium
    c) Copper

**Long answer questions**

25. What is concentration of ore?
26. Define metallurgy.
27. Explain the types of metallurgies.
28. Explain Roasting. Which one ores are subjected roasting?
29. Why calcination of ore is essential?Explain calcination
30. Define Smelting
31. What are alloys? What are the purposes of making alloys?
32. Mention the various steps involved in the extraction of metal from their important ores.
33. What is difference between hydrometallurgy and electrometallurgy?
34. Explain in brief froth floatation process.
35. Write a short note on gravity separation or levigation process or hydraulic washing.
36. What are the applications of following alloys
    a) solder.
    b) nichrome
    c) duralumin
    d) alnico
    e) brass
    f) bronze
37. Define refining of metal.

**Answers to objective type questions**:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | b | 2. | b | 3. | a | 4. | d | 5. | c |
| 6. | c | 7. | d | 8. | b | 9. | d | 10. | a |

# UNIT - 7

## FUEL

**Learning Objectives:** By learning this unit students will be able to:

- explain chemistry of fuel and their recourses.
- recognize characteristics of good fuel.
- understand calorific value of a fuel and its units
- differentiate different types of fuels
- understand fuel quality in terms of octane and cetane numbers
- determine moisture and ash content (proximate analysis) of coal

**7.1 FUELS:** The combustible substances which on burning produce large amount of heat that can be used for domestic and industrial processes are called fuels.

**7.1.1. Classification of fuels**

**a) On the basis of physical state:**On the basis of physical states fuels are of three types:

**Solid fuels:** wood, coal, charcoal, coke is example of solid fuels.

**Liquid fuels:** crude oil, petrol, diesel, kerosene oil, power alcohol, are example of liquid fuels.

**Gaseous fuels:** natural gas, bio gas, water gas, producer gas, oil gas and CNG are example of Gaseous fuel.

**b) On the basis of source: On the basis of source fuels are of two types:**

1) **Natural Fuels or Primary Fuels:** The fuels which occur in nature are callednatural fuels. For example wood, coal, crude oil, natural gas
2) **Artificial or secondary fuel**: The fuels which are prepared artificially are called natural fuels. For example charcoal, coke, petrol, diesel, keroseneoil, power alcohol, water gas, producer gas, oil gas.

**7.2 CALORIFIC VALUE:** The total amount of heat produced by complete combustion ofunit amount of fuel is called calorific value.In CGS system calorie/gramis the unit of calorific value. In SI system kilo joules/kilograms (kJ/kg) is the unit of calorific value of solid or liquid fuels and generally gaseous fuels calorific value will be expressed as kilo joules/ cubic meter ($kJ/m^3$).

**7.3 CHARACTERISTICS OF GOOD FUEL:**A good fuel should possess following Characteristics:

1) **High Calorific value**: A good fuel should possess high calorific value that is it should produce large heat on combustion.
2) **Moderate ignition temperature:** Low ignition temperature is dangerous for storage and transportation and high ignition temperature cause difficulty in burning of fuel. So a good quality fuel should have moderate ignition temperature.

3) **Low moisture content**: A good fuel should have low moisture content because moisture decreases calorific value of fuel.
4) **Cheap:** A good fuel should be cheap and easily available.
5) **Easy transportation**: A good fuel should be easily transported from one place to other.
6) **Controllable combustion**: A good fuel is that whose combustion can be easily controlled.
7) **Low ash (non combustible matter content)**: Non combustible substance left after burning fuel is called ash. It reduces calorific value, so a good quality fuel should not contain ash.
8) **Moderate rate of combustion**: The rate of combustion of good quality fuel should be low.
9) **Low storage cost**: The storage cost of a good quality fuel should be low.
10) **Minimum smoke and poisonous gases**: The gaseous products of combustion of fuel should not pollute the atmosphere.

**7.3.1 Advantages (merits) of gaseous fuel over solid fuels:**

The advantages of gaseous fuel over other solid of fuels are:

1) **High Calorific value**: The calorific value of gaseous fuel is high calorific value as compared to solid and liquid fuel.
2) **No smoke and poisonous gases**: The gaseous fuel on burning, do not produce any smoke.
3) **Easy transportation**: A gaseous fuel should be easily transported from one place to other with the help of pipelines.
4) **Controllable combustion**: The combustion of gaseous fuel can be easily controlled by using knob.
5) **Economical:** The gaseous fuel is cheap as no extra heat is required for igniting them. The hot waste gaseous can be reused in certain operations
6) **Easily lightened:** The gaseous fuel can be easily lightened.
7) The flame can be made oxidizing, reducing and normal by regulating air supply to burner.

**7.4 PROXIMATE ANALYSIS OF COAL:**The determination of percentage of moisture, volatile matter,ash and fixed carbon in coal is known as proximate analysis of coal.

**a) Determination of moisture**: The known weight of powdered dried coal sample is taken in a crucible which is already weighted. The crucible is heated in a hot air oven at 100-110 $^{o}$C for one hour. After this, the crucible is taken out, cooled and weighted again. The process of heating, cooling and weighing is repeated till constant weight is obtained. Knowing the loss in weight of coal, the percentage of moisture is calculated as:

Weight of crucible= x g

Weight of crucible + Coal = y g

Weight of crucible + residue (Coal without moisture) = z g

Weight of coal = (y-x) g

Weight of moisture = (y-z) g

So Percentage of moisture $= \frac{\text{weightofmoisture}}{\text{weightofcoal}}$ X 100

$= \frac{(y-z)}{(y-x)}$ X 100

**b) Determination of volatile matter**: The known weight of moisture free coal sample is taken in a crucible which is already weighted. The crucible is heated in a muffle furnace at 925$\pm$25$^{o}$C for 7 minutes. After this, the crucible is taken out, cooled and weighted again. The process of heating, cooling and weighing is repeated till constant weight is obtained. Knowing the loss in weight of coal, the percentage of volatile matter is calculated as

Weight of crucible= x g
Weight of crucible + Coal = y g
Weight of crucible + residue (Coal without volatile matter) = z g
Weight of coal = (y-x) g
Weight of volatile matter = (y-z) g

So Percentage of volatile matter $= \frac{\text{weightof volatile matter}}{\text{weightofcoal}}$ X 100

$= \frac{(y-z)}{(y-x)}$ X 100

**c) Determination of ash:** The known weight of coal after determination of moisture and volatile matter is taken in a crucible which is already weighted. The coal in crucible is heated in a muffle furnace at 700+ 50$^{o}$C for 30 minutes. After this, the crucible is taken out, cooled and weighted again. The process of heating, cooling and weighing is repeated till constant weight is obtained. Knowing the weight of residue (ash), the percentage of ash is calculated as

Weight of crucible= x g
Weight of crucible + Coal = y g
Weight of crucible + residue (ash) = z g
Weight of coal = (y-x) g
Weight of ash (residue) = (z-x) g

So Percentage of ash $= \frac{\text{weightofashformed}}{\text{weightofcoal}} \times 100$

$= \frac{(z-x)}{(y-x)} \times 100$

**7.4.1 Importance of proximate analysis of coal:** Proximate analysis is useful in determining the quality of coal.

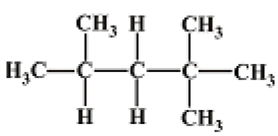
It gives following in formations

1) Moisture: Moisture evaporates during burning of coal and reduces calorific value of coal. So, lesser the moisture content, the better is the quality of coal.

2) Volatile matter: The volatile matter present in coal burns with high flame and reduce calorific value of fuel. So, lesser the volatile matter, the better is the quality of coal.
3) Ash: Non combustible substance left after burning coal is called ash. It causes hindrance in the flow of heat and reduces calorific value, so a good quality fuel should not contain ash.
4) Fixed Carbon: Higher percentage of fixed carbon , greater the calorific value , So, in a good quality coal the percentage of fixed carbon should be high

**7.5 FUEL QUALITY RATING:**To rate the quality of fuel is called fuel quality rating. There is different parameter to rate the quality of fuel. Octane number is used to rate the quality of petrol while cetane number used to rate the quality of diesel.

**7.5.1 Octane number:**The percentage of iso- octane by volume in the mixture of iso-octane and n-heptane which has same ignition (knocking) properties as the petrol under examination is called octane number of petrol. Octane number is used to determine to quality of petrol.

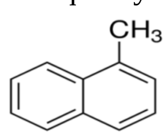


$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$

Iso octane
octane number=100

n- heptane
octane number=0

**7.5.2 Cetane number**:The percentage of cetane (n-hexadecane) by volume in the mixture of cetane and α-methyl naphthalene which has same ignition (knocking) properties as the diesel under examination is called cetane number of diesel. Cetane number is used to determine to quality of diesel.



α- methyl naphthalene
Cetane number= 0

**$CH_3(CH_2)_{14}CH_3$**
Cetane ((n-hexadecane)
Cetane number=100

**7.6 GASEOUS FUEL-COMPOSITION, CALORIFIC VALUE AND APPLICATION OF CNG:**

CNG is known as Compressed Natural Gas.It mainly containsmethane and may contain small amount of ethane and propane which are compressed at high pressure. It burns completely and reduces pollution. Uses/ Application: It is being used as a fuel for running automobiles i,e buses, cars and three wheeler in metropolitan cities.

**7.6.1 Gaseous fuel-Composition, calorific value and application of LPG:** LPG is known as Liquefied Petroleum Gas. It is the mixture of hydrocarbons containing 3-4 carbon atoms. It mainly contains iso-butanealong with small quantity of n-butane, propane and propene. A strong smelling substance called ethyl mercaptan ($C_2H_5SH$) is added to detect its leakage.The calorific value of LPG is 27800 kcal/ $m^3$.

Use: LPG is mainly used domestic and industrial fuel. Now a day it is used as motor fuel.

**7.6.2 Gaseous fuel-Composition, calorific value and application of biogas:**

Biogas is produced by bacterial degradation of biological matter in the absence of air.The cheapest biogas is gobar gas.

**Composition**: The average composition of biogas is

Methane ($CH_4$)=55%

Carbon dioxide ($CO_2$)= 35%

Hydrogen ($H_2$)=8%Nitrogen ($N_2$)=2%

**Properties**:

1. It burns with blue flame
2. It burns with low flame.
3. Its gross calorific value is 12000 kcal/$m^3$.

**Uses**:1. It is used as domestic fuel in villages.

2. Used animal waste to go out for manure

**Questions for Revision**

1. Which of the following are primary (natural) fuels?

a) coal b) LPG c) crude oil d) both a & c

2. S I unit of calorific value ________

a) kJ/$m^3$ b) kJ/kg c) both a & b d) none

3. Which fuels have higher calorific value?

a) Solid b) Liquid c) Gaseous d) All

4. 10 grams of coal sample on heating in muffle furnace and cooling to room temperature produce 1000 mg of ash. Therefore its ash percentage will be:

a) 100% b) 10% c) 90% d) 80%

5. 5 grams of coal sample on heating in oven and cooling to room temperature loose 300 mg mass. Then its moisture percentage will be:

a) 1% b) 60% c) 6% d) 40%

6. 20 grams of coal on complete combustion produce 600 kJ of heat and its calorific value is

a) 3000 kJ/kg b) 30000 kJ/kg c) 300 kJ/kg d) 30 kJ/kg

7. Petrol quality is rated by using its, ______________ number

a) cetane b) octane c) decane d) all

8. Diesel fuel is rated by using its, _________ number.

a) cetane b) octane c) decane d) all

9. _____________ of the following is secondary or artificial fuels.

a) CNG b) LPG c) Crude oil d) Both a & b

10. Which of the following statement is incorrect?

a) Any substance on complete combustion will produce efficient and use full energy is called fuel.

b) Calorific value of good fuel will higher

c) Good solid fuel should produce high ash.

d) Good fuel would produce minimum smoke.

**Short answer questions**

11. How will coal be rated based on its carbon percentage?
12. What is the full form of LPG?
13. Expand CNG.
14. Define Fuels.
15. Define calorific value.
16. What is ignition temperature?
17. Give any one example of liquid fuel.
18. Mention natural
    a) Solid fuels.
    b) Liquid fuels.
    c) Gaseous fuels.
11. Give examples to the following types of secondary fuels:
    a) Solid fuels
    b) Liquid fuels
    c) Gaseous fuels

**Long answer questions**

12. What are secondary fuels? Give example
13. Give the SI units of solid or liquid fuel and gaseous fuels.
14. A sample of coal on complete combustion produces 15500 kJ of heat energy. Calculate calorific value of coal in kJ/kg.
15. What is the difference between gross calorific value and net calorific value?
16. Give in brief classification of fuels along with examples.

17. Write all characteristics of good fuel.
18. How will you calculate the percentage of ash in a given sample of coal?
19. Explain in detail the proximate analysis to determine the quality of coal.
20. Give importance of proximate analysis.
21. What are the advantages of gaseous fuel over liquid and solid fuel?
22. Write a short note on cetane number for diesel.
23. Write a short note on octane number for petrol. Or Explain octane number for petrol
24. Give the composition, Preparation and uses of biogas.
25. Write a short note on LPG.
26. What is its composition and application of CNG.

**Answers to objective type questions:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | d | 2. | c | 3. | c | 4. | b | 5. | c |
| 6. | b | 7. | b | 8. | a | 9. | d | 10. | c |

# UNIT - 8

## WATER

**Learning Objectives:** By learning this unit students will be able to:

- understand importance of water and its shortage.
- recognize different types of natural water and causes of impurities in water.
- understand and qualitatively identify soft and hard water.
- recognize salts responsible of water hardness and differentiate different types of hardness.
- express hardness of water in different units.
- understand different problems caused by use of hard water in industries and domestic application of water.
- understand quality characteristics of drinking water.

**8.1 TYPES OF WATER:** Water is classified two types based on the behavior with soap. These are:Soft water: The water which forms lather with soap easily is called soft water.It contains no dissolved salts in it.Example Rain water, distilled water, demineralized water.Hard water: The water which *not* forms lather *with soap easily* is called hard water.It contains dissolved salts of anions like $SO_4^{2-}$, $CO_3^{2-}$ , $HCO_3^{1-}$ withcalciumand magnesium in it. Tap water, river water, spring water, sea water are some of theexamples of hard water.

**8.1.1** Causes of hardness of water:Hardness of water is caused by the presence of soluble salt of calcium and magnesium that is bicarbonates, chlorides, sulfate of calcium and magnesium. Action of hard water on soap:

When hard water is added with the potassium and sodium salt of fatty acids (soap), calcium and magnesium ions of hard water react with soap and forms insoluble curd of fatty acids. So lots of soap is wasted and hard water is not considered suitable for washing purposes.

**8.2 TYPES OF HARDNESS:**Hardness of water is of two types:

a) Temporary hardness ii)Permanent hardness

**8.2.1** Temporary hardness of water:The hardness of water which can be simply removed by boiling the water is known as temporary hardness.

Cause of Temporary hardness:Temporary hardness is due to the presence of bicarbonates of calcium and magnesium. This type of hardness is removed by boiling the water.

**8.2.2** Permanent hardness of water:The hardness of water which cannot be removed by simple boiling the water is called permanenthardness.

**8.2.3** Cause of Permanent hardness:Permanent hardness of water is due to the presence of chlorides and sulfates of calcium and magnesium. This type of hardness is removed by washing soda process.In commercial scale, temporary hardness is removed by Clarke’s process.

**8.3 UNITS OF HARDNESS OF WATER**:The hardness of water is caused by the presence of soluble bicarbonates ($HCO_3^{-1}$), chlorides ($Cl^{-1}$), sulfate ($SO_4^{-2}$) of calcium ($Ca^{+2}$) and magnesium ($Mg^{+2}$). But hardness of water is measured in terms $CaCO_3$ equivalents of these hardness causing substances.Degree of hardness in ppm (parts per million):The number of parts by mass of hardness causing substances interms of $CaCO_3$present per million ($10^6$) parts by mass of water is called parts per million (ppm). These concentrations are very low and practically assume the density of water unchanged that is 1 g/mL. Thus, it can be expressed as 1 parts per million = 1 ppm = 1 mg/L

Example: If hardness of water is 200 ppm, it means hardness of water in terms of $CaCO_3$ is 200 parts by mass in $10^6$ parts by mass of water.ppm is also termed as mg/L.

Example A sample of water is found to contain 0.30 g $MgSO_4$ per liter. Calculate its hardness in ppm?(Atomic masses of Mg=24, Ca=40,C=12,S=32 and O=16 respectively)

Solution: $MgSO_4 \equiv CaCO_3$

24+32+ 4X16=120 40+12+4X16=100

$$120 \text{ g of } MgSO_4 \equiv 100\text{g of } CaCO_3$$

$$0.30 \text{ g of } MgSO_4 \equiv \frac{100}{120} X 0.30 \text{g of} CaCO_3 = 0.25 \text{ g of } CaCO_3$$

Thus,hardness causing substances in terms of $CaCO_3$=0.25g/liter

i,e 1 liter water = 1000g of water contain=0.25 g of $CaCO_3$

$$10^6 \text{g of water contain} = \frac{0.25}{100} X 1000000 \text{g of } CaCO_3 = 250\text{g of } CaCO_3$$

So, Hardness of water= 250 ppm

Example: A sample of water is found to contain 9.5 mg $MgCl_2$ per liter. What will be its hardness in ppm?(Atomic masses of Mg=24, Ca=40,Cl=35.5, and O=16 respectively)

Solution $MgCl_2 \equiv CaCO_3$

24+35.5x2=95 ≡ 40+12+4x16=100

95mg of $MgCl_2$ ≡ 100 mg of $CaCO_3$

9.5mg of $MgCl_2$ $\equiv \frac{100}{95}$X9.5 mg of $CaCO_3$ =10mg of $CaCO_3$

Thus,hardness causing substances in terms of $CaCO_3$=10 mg/liter

i,e. 1 liter or 1000g of water contain=10 mg of $CaCO_3$

$10^6$mg of water contain=10 mg of $CaCO_3$

So, Hardness of water is =10 ppm

## 8.4 DISADVANTAGES OF USING HARD WATER IN BOILER:

In industries, water is largely used in boiler for generation of steam. Hard water if used in boiler gives rise to following defects:

i) Formation of scale and sludge
ii) Corrosion
iii) Caustic embitterment
iv) Primming and foaming.

**8.4.1** Scale and Sludge formation:

Scale: The hard, adherent and thick layer (crust) formed on the inner walls of boiler is called Scale.

Sludge: The soft, loose and thin layer (crust) formed on the inner walls of boiler is called Sludge.

Disadvantages of scale and sludge formation:

i) Wastage of Fuel: Scale and sludge are bad conductors of heat, so rate of transfer of heat from boiler walls to water decrease which results wastage of fuel.
ii) Decrease in efficiency of boiler:Due to the formation of scale and sludge the area of cross section of boiler pipes decreases, so rate of formation of steam decreases i.e efficiency of boiler decrease.
iii) Chances of explosion increase:If water enters in cracks of scale and sludge and formation of steam develop huge pressure, then chances of explosion will increases.
iv) Shorten boiler life:Scale and sludge are bad conductors of heat, so rate of transfer of heat from boiler walls to water decrease and overheating of boiler pipes to maintain the steady supply of steam. Due to overheating of boiler pipes, it becomes weak.

**8.4.2** Corrosion: The slow and continuous eating of boiler pipes of boiler is called corrosion.

Disadvantages of corrosion:

i) Corrosion decreases the life of the boiler.
ii) The cost of repair and maintenance of boiler increase.
iii) Chances of leakage of boiler pipes from joints and rivets increase.

**8.4.3** Caustic embitterment: The leaking (cracking) of boiler pipes and plates from joints and rivets when it becomes brittle due to the presence of alkaline substances in boiler feed water is called caustic embitterment.

Disadvantages of caustic embitterment:

i) Caustic embitterment decreases the boiler life.

ii) The cost of repair and maintenance of boiler increase.
iii) Efficiency of boiler decreases due to leakage.

**8.5 QUALITY OF DRINKING ( POTABLE) WATER**:The drinking (potable) water should satisfy the following characteristics:

1. Drinking water should be soft.
2. It should be colorless.
3. It should beodourless.
4. The pH of drinking water should be 6.9 to 8.5.
5. It should be free from disease- producing micro-organisms.
6. The hardness of drinking water should not be more than 200 mg /L or 200ppm.
7. The alkalinity of drinking water should not be greater than 200ppm or 200 mg/L.
8. It's TDS (total dissolved solid) should not be greater than 500ppm.
9. It should not be turbid.
10. It should not contain suspended impurities.
11. It should not contain impurities of heavy metals.
12. It should be tasteless.

Hardness of water in ppm can be used to calculate using following formula. Assuming density of hard water unchanged.

$$\text{CaCO}_3 \text{ equivalent hardness due to \_\_\_\_\_\_\_} = \frac{\text{Mass of hardness causing substances x 100}}{\text{Molar mass of hardness causing substances x volume of hard water in L}}$$

For example to calculate hardness of water containing 9.5 mg of $MgCl_2$ per liter of water in ppm above mentioned equation can be directly used. By substituting values in the equation

$$\left.\begin{array}{l}\text{CaCO}_3 \text{ equivalent hardness due to 9.5} \\ \text{mg of MgCl}_2 \text{ per liter of water}\end{array}\right\} = \frac{9.5 \text{ x } 100}{95 \text{ x } 1} \text{ ppm} = 10 \text{ ppm}$$

**Questions for Revision**

1. The percentage of natural water available for direct use is approximately______

a) less than 10% b) more that 80% c) less than 0.5% d) 100%

2. Simple qualitative test of water hardness is ________ action test.

a) oil b) water c) litmus d) soap

3. The presence of _______salts responsible of temporary hardness of water.

a) $HCO_3^{-1}$ of $Ca^{+2}$& $Mg^{+2}$ b) $Cl^{-1}$ of $Ca^{+2}$& $Mg^{+2}$ c) $SO_4^{-2}$ of $Ca^{+2}$& $Mg^{+2}$ d) all

4. The presence of _______salts responsible of hardness of water.

a) $HCO_3^{-1}$ of $Ca^{+2}$& $Mg^{+2}$ b) $Cl^{-1}$ of $Ca^{+2}$& $Mg^{+2}$ c) $SO_4^{-2}$ of $Ca^{+2}$& $Mg^{+2}$ d) all

5. The unit of water hardness is

a) mg/L b) ppm c) $^{O}$ Fr d) all

6. The hardness of water containing 95 mg $MgCl_2$ per liter of water in ppm =
(Atomic masses of Mg = 24 and Cl = 35.5)

a) 95 ppm b) 950 ppm c) 100 ppm d) 10ppm

7. Scale and sludge formation is the problem caused by the use of hard water in_____

a) Paper industry b) boiler c) domestic d) all

8. ________ hard water can produce sufficient lather to soap solution on boiling.

a) Permanent b) Temporary c) Soft d) none

9. In India water quality of _______ are recommended.

a) ISI b) RO c) BIS d) MCI

10. The hardness of water containing 95 mg $MgCl_2$ and 162 mg $Ca(HCO_3)_2$ per liter of water in ppm =
(Atomic masses of Mg = 24 and Cl = 35.5, Ca=40, C=12, H= 1, and O =16)

a) 200 ppm b) 100 ppm c) 95 ppm d) 162 ppm

**Short answer questions**

12. Mention domestic applications of water.
13. What are industrial applications of water?
14. Name the salts in water responsible for temporary hardness of water.
15. Name the salts in water responsible for permanent hardness of water.
16. How temporary hardness of water can be removed?
17. How do you test hardness of water qualitatively?
18. Why water is called universal solvent?
19. Define unit of water hardness.
20. Degree of hardness is measured in terms of ______
21. Which is considered to be purest form of water?

22. Which is natural water is considered to be most impure form of water?
23. Expand TDS, BIS and ppm

**Long answer questions**

24. Define Soft Water.
25. Write differences between permanent and temporary hardness of water.
26. Write explanatory note on degree of hardness of water (ppm).
27. Explain reverse osmosis.
28. Explain the disadvantages of using hard waterin boiler.
29. What is scale and sludge? Give its disadvantages.
30. What do you mean by caustic embitterment? Give its disadvantages.
31. Mention the quality characteristics ofdrinking (Potable water).
32. A sample of hard water is found to contain 204 mg of $CaSO_4$per liter,calculatehardness of water in ppm.

**Answers to objective type questions:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | c | 2. | d | 3. | a | 4. | d | 5. | d |
| 6. | c | 7. | b | 8. | b | 9. | c | 10. | a |

# UNIT - 9

## LUBRICANTS

**Learning Objectives:** By learning this unit students will be able to:

- understand lubricant, lubrication and mechanism of lubrication and importance of lubrication.
- identify the chemical and physical properties of lubricant for specific lubrication.
- understand and qualitatively and quantitative measurement of few physical and chemical properties of lubricants.
- explain mechanism of lubrication to be used for machines under service conditions.

**9.1INTRODUCTION**: We know that due to corrosion smooth surface become rough.If in different parts of machines, corrosion occurs then they will also become rough which not move smoothly and their (efficiency working) will decrease due to obstruction created by corrosion. This obstruction in moving parts in called friction.

i) So friction is the force that opposes the relative motion of two surfaces sliding against each other. Examples: Rubbing both handstogether to create heat is due to friction.

ii) An object pushing along a floor.

iii) Frame and edge of door sliding against each other.

iv) The bottom of books sliding against table.

But friction is a necessary evil. Due to friction between our shoes and floor stops us from slipping. Friction between tyres and a vehicle stop the vehicle from skidding due to friction we can slow down anything.

**Problems due to friction:** As friction is a resistance that slow down or stop motion. So it can be a problem for:-

a) Machines will not work efficiently and their efficiency will reduce.

b) Machine will become noisy and will difficult to move and will also produce heat.

c) To move machines we have to put more power and resources.

d) Friction wears out the different parts which will require repairing.

e) To remove friction we have to make surfaces smooth by applying some substance like oil, grease, so we need to lubricate machines.

**9.2 DEFINITION OF LUBRICANT**: Lubricant is a substance which is applied between two surfaces to reduce friction and allow smooth movement of two surfaces Some example of lubricant are oil, grease, wax, polish etc.

**Lubrication:** The process of applying a lubricant such as oil or grease to the surfaces to make surface smooth and minimize friction is known as lubrication.

**9.3 FUNCTIONS OF LUBRICANTS:** Without lubrication it is not possible to move any vehicles or machines. A Lubricant performs many functions;some of them are described below:

i) It gives lubrication or oiling by keeping two sliding surfaces.
ii) Lubricants protect the different parts of machines from wear and tear.
iii) A Lubricant gives cooling effect by reducing friction.
iv) It decreases the force of friction between sliding surfaces.
v) It decreases the maintenance and running cost of machine.
vi) It reduces the noise level during running of machine.
vii) It increases the efficiency of machine.

**9.4 CLASSIFICATION OF LUBRICANTS:** Lubricants can be simply classified into three main types:

1. Liquid Lubricants or lubricating oils
2. Semi Solid Lubricants or greases
3. Solid Lubricants

**1. Liquid Lubricant:** These types of Lubricants include mineral oil, vegetable oil and animal oil.

**(i) Mineral oil**: Mineral oils of higher hydrocarbon and thick so by mixing with vegetable oil they can be made thin. These are cheap and easily available. These are obtained by fractional distillation of petroleum at about 4000°C. They are cheap and available easily in abundance. These contain impurities like wax. Their oiliness can be improved by adding oleic or steric acid.

**(ii) Vegetable oil**: These are obtained from vegetables which include

a) **Olive oil**: Obtained from olive tree and is used for lubrication of bearings.
b) **Palm oil**: Obtained from kernels of Palm and is used for Lubrication of watches and clocks.
c) **Castor oil**: obtained from seeds of castor and is used for lubricants of vehicles and bearings

**(iii)Animal oil:** These are obtained from different animals.

**a) Neat foot oil** :obtained from neat by boiling in with water and is used for lubrication of sewing machines, watches & clocks
**b) Whale oil** : used for light machinery
**c) Lord oil** : obtained from kidneys and fats of pigs and is used for various machine

**d) Blended oil**: it is mixture of animal or vegetable oil with mineral oil. It is a good lubricant. It is done to reduce pour point improve viscosity, increase oiliness and resist oxidation. Example: mixture of coconut oil and fatty acid to increase oiliness and polystyrene for thickness.

**e) Synthetic oil**: These type of lubricants are chemically prepared compounds. These are used when mineral oils do not work. They are used in jet engines rocket motors.

**2. Semi Solid Lubricants**: These Lubricants include grease and emulsion.

**(i) Greases:** This include metallic soap in lubricating oil. It is usedwhen

- Machine is working at low speed and high load.
- For stealing bearing against dirty and dust particles
- When lubricating oil is not suitable for machines.

Grease is of following types:-

a) **Calcium based Grease:** obtained by mixing calcium soap with petroleum oil. It isused for lubricating of water pumps & workshop.

b) **Soda based grease:** obtained by mixing sodium soap with petroleum oil and is used for ball bearing

c) **Lithium based grease:** By mixing lithium soap with petroleum oil and is suitable at high temperature

d) **Axle grease:** By adding hydroxides of metal to fatty acids. These are water resistant and used in tractors rollers and machines bearings

**(ii) Emulsion bearings:** These are obtained by mixing twoimmiscible liquid by using high speed machines. These are used in many machines. They include two phase system in which one liquid will act as disperse phase and others dispersion medium.

**3. Solid Lubricant:** These are present in solid form. They are used in heavymachines with high load and low speed. The two main solidlubricants are graphite and molybdenum disulphide. These are used where oil and grease are undesirable.

**i) Graphite:** It is a crystalline substance and allotropes of carbon. Its density is low. It forms a lubrication film which remains strongly adhered to the surface of machine. This graphite film provides good resistance to wear and tear. Graphite contains layers of carbon atoms which slide over each other because they have weak forces between them making graphite slippery. **Uses**: It is used in steel industry. It is used to make brake liningsused in air compressor ball bearings and in locks.

**ii) Molybdenum disulphide:** ($MoS_2$) it is an inorganic compound composed of molybdenum & sulfur. It has a layered structure in which molybdenum atoms are sandwiched in planes of sulfide ions. It is used as lubricants n in motorcycle engine, bullets.

**9.5 TYPES OF LUBRICATION**: Lubrication is the process of using lubricant to reduce friction between two surfaces in contact. Lubrication gives oiliness to the surface thus making it smooth by reducing friction. It is of mainly two types.

**(i) Hydrodynamic Lubricationor Thick Layer Lubricationorfluid film lubrication:**t is used in those machines where speed is high and load is very low. This type of lubrication is done in case of delicate instruments like watches, clocks, guns, sewing machine and scientific instruments. In this type of lubrication, the lubricant fill the irregularities of moving surface and form a thick layer (1000Å) in between them so that there is no contact between the sliding surface. Here lubricant used should be viscous fluids and load is taken by oil film completely.

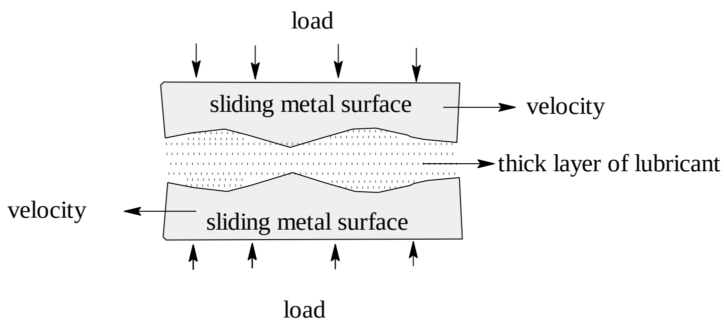



Fig 9.1 Fluid film lubrication

This type of lubrication is done with liquid lubricants having minimum viscosity under working condition. The lubricant should remain between and separate the sliding surface of machine. The resistance to movement of sliding parts is only due to the viscosity of the lubricant. So lubricant should be chosen in such a way that it posses minimum viscosity under working condition.

**(ii) Boundary Lubrication** (Thin Film of Lubrication): It is used when speed is very low and load is very high and also when shaft starts moving from rest. It exists when it is not possible to form a full fluid condition especially at low speed between the moving surfaces.

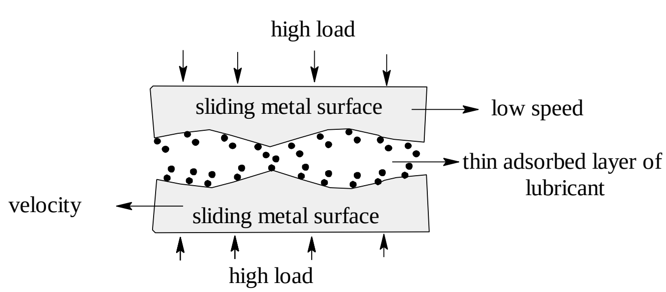



Fig 9.2 Thin Film of Lubrication

The lubricating oil is filled between the sliding surfaces, which is adsorbed on both metallic surfaces by any physical or chemical forces. The adsorbed layers avoid metal to metal contact.The load is carried by the layers of adsorbed lubricant on both metal surfaces.Vegetable oil and animal oils and their soaps possess great property of adsorption and are used in thin film lubrication. Graphite or molybdenum disulphide either alone or in the form of suspension are also used in thin film lubrication.In boundary lubrication thickness of oil film is so small that oiliness is restricted mainly to the boundaries of two surfaces. The thin film lubrication is done in piston rings when piston changes direction and in two stroke engines & lubrication of bearing in Diesel engine.

**Difference between hydrodynamic and boundary lubrication:**

| Hydrodynamic Lubrication (Thick Layer of Lubrication) | Boundary Lubrication (Thin Layer of Lubrication) |
|---|---|
| 1. Lubricants having low viscosity are used in this lubrication. | 1. Lubricants having high viscosity are used in this. |
| 2. These are used in machines having light load and high speed. | 2. These are used in machines having heavy load and low speed |
| 3. The load applied is sufficient to keep away of moving surfaces. | 3. Here is load is carried by layer of applied lubricants |
| 4. Here thickness of lubricating film is more than 100 Å | 4. Here thickness of lubrication is less than 100 Å |
| 5. Examples : Watches, Clocks, guns, Sewing machines | 5. Examples: Rollers Gears, Tractors and Railway track joints. |

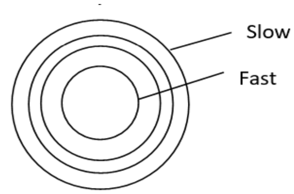
## 9.6 PROPERTIES OF LUBRICANT:

Physical properties of a Lubricant include some basic properties such as (i) Viscosity (ii) Viscosity Index (iii) Cloud point and Pour point (iv)Flash point (v) Fire point and (vi) Oiliness.

These are described below:

i) **Viscosity**: Viscosity means thickness – A fluid which is more viscous mean thick fluid. Example: Honey is more viscous (thick) than water.

Definition: Viscosity of a liquid may be defined as the property of a liquid by virtue of which it resists its flow (oppose its flow). orThe force of friction which one part of liquid offer to other part to resist its flow is called viscosity.Unit: In SI system unit of viscosity is newton second per square meter ($Ns/m^2$)



**Significance:** Machines moving at slow speed should use more viscous lubricant and machines with high speed should use less viscous fluid.

**(ii) Viscosity Index:**The rate of change of viscosity of lubricant withrespect to temperature is called viscosity index.It has been seen that viscosity of lubricant changes with change in temperature. Low viscosity index means viscosity of lubricant falls rapidly with temperature and high viscosity index means viscosity does not fall rapidly with temperature. It is measured on a scale from 0 to 100.

**Significance of viscosity index** A fluid lubricant should have high viscosity index(otherwise it will create problem)

**(iii) Cloud point and pour point**: The temperature below which a lubricant form a cloudy appearance on cooling and pour point is that temperature at which oil ceases to flow (as its turn into semi solid and loses its flow characteristics). So if lubricant ceases to flow machine may stop and its working will effect.

**Significance:** A good lubricant should have low pour point so that it can be used at low temperature. Olive oil begins tosolidify at around 4 $^oC$.So by to knowing cloud point and pour point we can know that at to what lowest temperature a lubricant can be used safely.

**(iv) Flash point:**Flash point of a lubricant may be defined as the lowest temperature at which it ignites for a very short moment (briefly) after vaporization but not continue to burn after ignition. Flash point is lower than fire point.

**Significance:** Flash point is very important because with the help of this we can find that at upto what temperature a lubricant can form an ignitable, mixture which will burn further on increasing of temperature. At flash point vapour may not be produced at a rate to sustain the fire Flash point of diesel fuel varies $52^0C$ to $96^0C$ depending on type of diesel fuel. It is also very important for proper handling of diesel fuel so flash points are experimentally calculated depending upon density and quality of a fuel.

**(v) Fire point**: Fire point of a lubricant is thatminimum temperature at which vapours of a lubricant continue to burn after being ignited even after source of ignition is removed (lubricant will continue to burn for at least 5 seconds). Fire point of a lubricant is few degree (near about $10^0C$) higher then flash point.

**Significance**: it gives an idea about risk of fire hazards during storage and use of fuel.This temperature point is very important because it helps in determining that how a fuel is transported and stored.

**(vi) Oiliness:**The property of lubricant to form continuous film even at high temperature and pressure is called oiliness.OrOiliness means covered with oil or greasy. “Oiliness is defined as property of a substance by virtue of which one fluid gives lower coefficient of friction than another substance of same viscosity”.OrOiliness can also be defined as “the capacity of lubricant to stick on the surface of machine under high pressure and load”. A good lubricant should have good (high) oiliness.

**Significance**: Oiliness of a lubricant reduces wear and friction under different conditions. So a lubricant should have proper oiliness required on the basis of its application.

**9.7 CHEMICAL PROPERTIES OF A LUBRICANT**: As we have studied Physical properties of lubricant. Similarly, Chemical properties of lubricant like (i) TAN, (ii) emulsification, (iii) aniline points and (iv) iodine nature. These properties are described below:

**(i) TAN or TAV**: TAN or TAV stands for total Acid Number or Total Acid value.

Definition:TAN or TAV: The amount of KOH (Potassium hydroxide) in milligrams required to neutralize the free acids present in one gram of lubricant (oil). Total Acid No is the measurement of acid present in the lubricant.

**Significance**: TAN No. is very important in selecting a good lubricant. Its value should be less than 0.1. if it is more than 0.1 then lubricant will oxidize easily which will further create corrosion problems.

Depending upon the oil’s formulation compressor oil may be able to maintain low TAN.

A good lubricant should have low acidity or TAN or TAV.

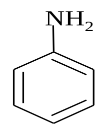
Determination of TAN No. **:** TAN can be determined by volumetric and potentiometric titrations.

**(ii)** **Emulsification**:Emulsion is a intimate mixture of oil and water so emulsification may be defined as **“Property of a lubricant to emulsify with water”.** Emulsion has property of absorbing dust particles and other foreign particles. These particles after combining with emulsion cause abrasion of metals and in this way role of a lubricant get disturbed.A good lubricant should not easily form emulsion. Thus, while selecting good lubricant emulsification should also be tested.

**Significance of emulsification:**It a lubricant is forming emulsion then it will be able to cause abrasion of metal and metal will become weak which will decrease the life of machine. A good lubricant should not form emulsion if emulsion if formed then it should be renamed or break quickly. No a day's refined lubricant are used which has very less chances of emulsion formation.

**(iii) Aniline point:**

Aniline is an aromatic organic compound: formula $C_6H_5$—$NH_2$or having phenyl group attached to amino group.



**Definition:** Aniline point may be defined as minimum temperature at which equal volume of lubricant (oil) and aniline is completely miscible or form homogeneous mixture.

**Significance:** A good lubricant should have adequate aniline value. If aniline point is low then content of aromatic compound in oil will be more. So this value gives an approximation for content of aromatic compounds in the oil. "High aniline point indicates that fuel is highly paraffinic and very good ignition quality.

Diesel oil with aniline point below $49^oC$ is probably risky to use.

**Determination of aniline point:** For the determination of aniline point equal volume of aniline and lubricants are stirred continuously until to form a homogeneous solution, when homogeneous solution is formed heating is stopped and solution is allowed to cool. The temperature at which two given compound (Aniline and aromatic compound (Lubricant)) separated out is called aniline point.

**(iv) Iodine value**: Iodine value is also very important chemical property of lubricant

**Definition**: The amount of iodine in grams taken up by 100 grams of lubricant (Oil, Fat or Wax) is called iodine value.

**Significance**: It is used to determine amount of unsaturated (C = C or C = C bond) "More the iodine value of lubricant more will be unsaturated compound present in it". Example: Saturated oil, fats and waxes take up no iodine (because of absence of double or triple bond) so there iodine value is zero.Olive oil is used for making soap because of low iodine value (having less unsaturated). On the other hand unsaturated lubricants have high iodine value (because of presence of double or triple bond.)Drying oil is used in point and varnish industry because these have high Iodine value (about 90).

**Determination of Iodine value**: Iodine value of a lubricant can be determined by volumetric titration using sodium standard thiosulfate solution and starch indicator.

**Questions for Revision**

1. Chemical substance that used to reduce frictional forces operating between two sliding metal surfaces is known as ______.

a) Oil b) Lubricant c) Lubrication d) none

2. In machine with high load and low speed ______________ lubrication is employed.

a) Boundary b) Fluid film c) Both a & b d) none

3. Unit of viscosity is ________.

a) $m^2/s$ b) centistokes c) poise d) all

4. Graphite can act as ________ lubricant.

a) solid b) liquid c) Semi liquid d) none

5. A lubricant viscosity varies rapidly with temperature is said to have ___viscosity index.

a) high b) low c) moderate d) all

6. A lubricant viscosity dose not vary rapidly with temperature is said to have ___viscosity index.

a) high b) low c) moderate d) all

7. The amount of KOH (Potassium hydroxide) in milligrams required to neutralize the free acids present in one gram of lubricant (oil) is known as ________

a) TAN b) Coke number c) Iodine value d) none

8. Flash point of lubricating oil is lower than its _____________ point.

a) Melting b) Boiling c) Fire d) Center

**Short answer questions**

9. What is viscosity?
10. Define viscosity and viscosity index?
11. Mention examples of high and low viscous liquids.
12. Name a non metal which can act as solid lubricant?
13. Define an emulsion?
14. Expand TAN
15. Define friction?
16. What is lubricant?
17. Give the function of lubricant.
18. Give two examples of animal oil which are used as lubricant.

19. In clocks, watches and sewing machine which type of lubrication is used?
20. Define oiliness?
21. Define flash point
22. Give the importance of flash point

**Long answer questions**

23. Explain thick film lubrication mechanism.
24. Describe thin film lubrication mechanism.
25. Write short note on
    a) Physical properties of lubricant.
    b) Chemical properties of lubricant.
26. Give important characteristic function of a good lubricant.

**Answers to objective type questions:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. | b | 2. | a | 3. | d | 4. | a |
| 5. | b | 6. | a | 7. | a | 8. | c |

# UNIT – 10

## POLYMER AND PLASTIC

**Learning Objectives:** By learning this unit students will be able to:

- explain the chemistry of various polymers and plastics.
- identify the chemical substances which can undergo polymerization.
- verify suitability and select polymer/ plastic material for engineering applications.

**10.1 POLYMER, MONOMER, AND DEGREE OF POLYMERIZATION:** In almost all different fields of life Polymers are largely used. Plastic buckets, cups, children toys, kitchenware and many more things are made up of Polymers.

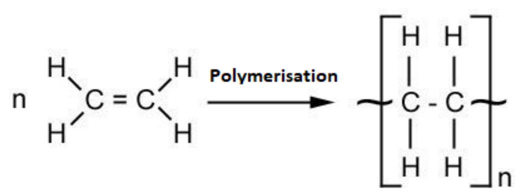
**Polymers**: Macromolecules obtained by combination of large number simple (small) molecules are called polymers. The polymer contains repeated structure units.All the macromolecules are not polymers but all polymers are macromolecules.OrPolymers are high molecular mass ($10^3$ - $10^7$μ) substances which consist of simple repeating structural units joined together by covalent bonds.

**Monomers**: Monomers are simple molecules from which repeating structural units (Polymers) are derived are called monomers.

Example ethene is monomer unit of Polyethene

The process by which simple molecules are converted into polymeris called Polymerization.

**Degree of Polymerization (DP)**:The number of repeating units which linked together to form polymer is called degree of Polymerization.




Ethene (Monomers)    Polyethene(Polymer)

Here ‘n’ units of ethene combine to form Polyethene. So ‘n’ is degree of polymerization.

**10.2 MONOMERS AND USES OF PE, PVC, PS, TEFLON, NYLON-6,6 AND BAKELITE:**

**1) Polyethene:** Monomer= Ethene. Polyethene is poor conductor of electricity. On the basis of density, low density and high density Polyethene are used for different purposes.

a) **Uses of Low Density Polyethene (LDPE):**
   i) These are transparent Polymers of moderate tensile strength. These are used as packaging material in the form of thin plastic films and bags.
   ii) Used in electric wires and cables as these are insulator of electricity.
   iii) In manufacture of squeeze bottles, toys and flexible pipes.

b) **High Density Polyethene:**
   HDPE have more toughness hardness and tensile strength
   **Uses:**
   i) It is used in the formation of containers like buckets, tubes.
   ii) It is used in house wares, pipes and bottles
   iii) It is also used for making toys for children.

3) **Poly Vinyl Chloride (PVC):**

**Monomer** – Vinyl Chloride

**Uses:**
i) It is used in making rain coat and shower curtains
ii) Used as insulator for Coating wires, Cables and other Electric Gadgets
iii) It is used for making hand bags.
iv) It is also used for making water pipes.

4) **PS (Polystyrene) :**
   **Monomer:** Styrene
   **Uses:**
   i) It is used for making Telephone, Radio, T.V. bodies and Refrigerator linings.
   ii) Used as wrapping material due to its insulator properties.
   iii) For making soft drink bottles.
   iv) Also used in making of baby feeding bottles.

5) **Teflon (Polytetrafluoroethene)**
   **Monomer**: Tetra fluoroethene
   <u>**Uses**</u>
   i) Because of its high thermal stability Teflon is used for making nonstick utensils. To make non-stick a thin layer of Teflon is coated on inner side of venal.
   ii) It is used for making gaskets.
   iii) It is used in no lubricating bearings and as filler of clothes.
   iv) It is also used in valves and seals.

6) **Nylon 6,6**
   Monomers – Hexamethylenediamine and Adipic acid. Nylon-6,6has high tensile strength and do not rot. It is tough and somewhat elastic material.
   **Uses:**
   i) It is used in manufacture of carpets textile fibers.
   ii) Used for making ropes and bristles for brushes
   iii) For making elastic hosiery
   iv) It is used as substitute for metals in bearings and gears.

7) **Bakelite:**

**Monomer**: Phenol and FormaldehydeBakelite is water resistant polymers and is a good electric insulator.

**Uses:**

i) It is used in making combs, fountain pen barrels computer disc and photograph record.
ii) Used in varnishes
iii) Used as binding glue for lamination
iv) Used as ion exchange resin in water filters
v) Also used in electric goods (switches, plugs) and also in making handles of utensils.

## 10.3 BRIEF INTRODUCTION TO ADDITION AND CONDENSATION POLYMERS; PE, PVC, PS TEFLON, NYLON6,6 AND BAKALITE.

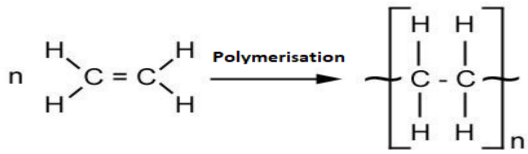
On the basis of mode of Polymerization the Polymers have been divided into two groups

(A) Addition Polymers and
(B) Condensation Polymers

(A) **Addition Polymers:**The polymers which are obtained by addition of monomer in growing polymeric chain are called addition polymer.

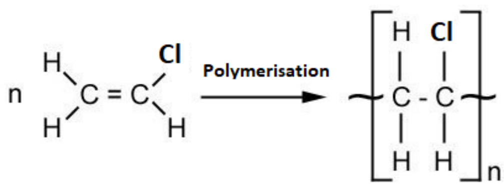
These are formed by repeated addition of large no of same or different monomers. This process of addition by which different polymers are formed is called addition polymerization. The different examples are given below:-

**(i) PE: Polyethene**



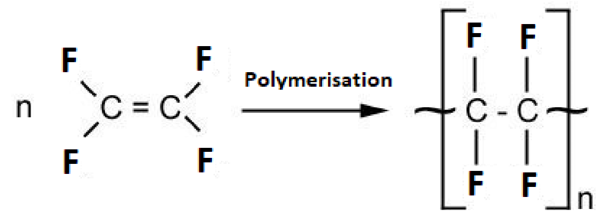

Ethene (Monomer) Polyethene (Polymer)

**(ii) PVC: Polyvinylchloride**



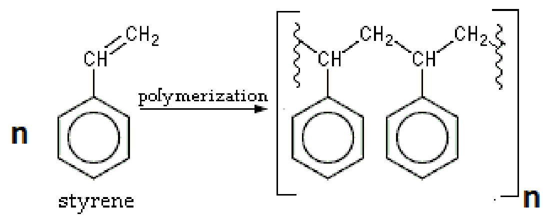

Vinyl Chloride Polyvinyl Chloride

**(iii) Teflon: PTFE (Polytetrafluoroethene)**




Tetra floroethylene Polytetrafloroethylene

**(iv) PS: Polystyrene**




Polystyrene

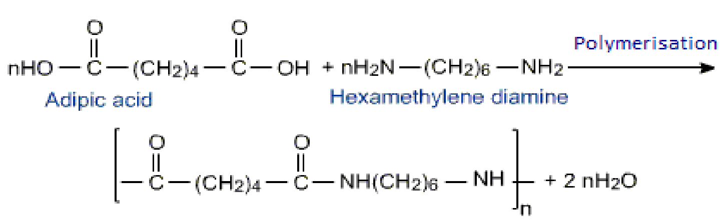
(B) **Condensation Polymers**:The polymers which are obtained by series of condensation reaction are called condensation polymers.

This type of Polymers are formed by repeated addition of large numbers of monomers molecules with elimination of simple molecules like $H_2O$, Alcohol and Ammonia takes place examples Nylon 66 and Bakelite.

**Examples**:

**i) Formation of Nylon 6,6**:

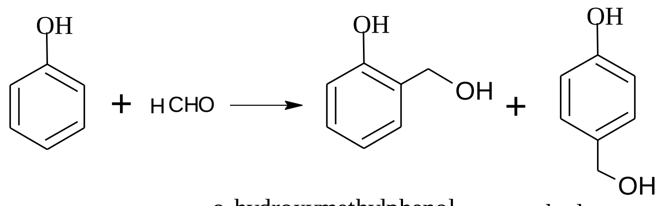
**Monomers:Haxamethylenediamine and adipicacid**both of these monomers combine or polymerise to form Nylon 6,6. This reaction takes place at 525 K and removal of n water molecules takes place.



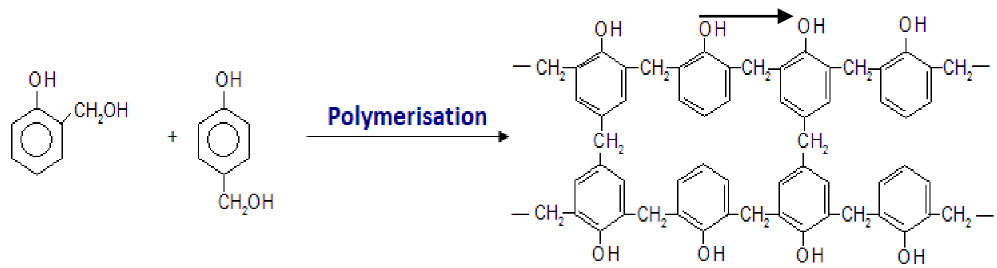

Nylon 6,6

**ii) Bakelite:**

**Monomers**:Phenol and Formaldehyde formortho-hydroxymethylphenol and para-hydroxylmethylphenol, both these polymerize to from Bakelite. This polymerization process also involves removal of n number of $H_2O$ molecules.




o-hydroxymethylphenol p-hydroxymethylphenol




ortho-hydroxymethylphenol + para-hydroxylmethylphenol →Bakelite

## 10.4 DEFINITION OF (A) PLASTICS (B) THERMOPLASTIC AND (C) THERMOSETTING POLYMERS AND DIFFERENCES

a) **Plastic**:

It is a group of materials either synthetic or naturally occurring which may be shaped when soft and then they are hardened to retain given shape. Plastic is also a Polymer.

b) **Thermoplastic**:

These are linear, slightly branched polymers which are hard at room temperature.These become soft and viscous on heating and again become rigid on cooling.

Example:Polyethene, Teflon and Polystyrene.

c) **Thermosetting Plastic:**

On heating these polymers undergo permanent change in chemical composition to give a hard; infusibleand insoluble mass. These are semi fluid whose molecular mass islow. They become hard after heating as due to the formation of cross link between different polymeric chains. Example: Bakelite

Table 10.1 Difference between Thermoplastic and Thermosetting Plastic

| Thermoplastic | Thermosetting Plastic |
|---|---|
| 1) It can be melted and recycled | 1) It cannot be melted and recycled. |
| 2) It is two-dimensional with no cross links | 2) It is three-dimensional with cross links |
| 3) It is prepared mostly by additional Polymerization | 3) It is prepared by Condensation Polymerization. |
| 4) These are mostly processed by conventional methods such as injection molding and below molding | 4) These are mostly processed by specific methods such as compression, transfer and casting |
| 5) These are used for making combs, toys, container & polybags etc. example : Polyethene, PVC and nylon | 5) Thermosetting plastic like melamine is used for making floors, tiles and kitchenwares. Bakelite is used to make electric switches. Example: Bakelite and melamine |
| 6) These are soluble in organic solvents | 6) These are not soluble in organic solvents |

## 10.5 USES OF POLYMER AND PLASTIC IN DAILY LIFE AND IN INDUSTRIES.

**(a) Uses of Polymers**: Polymers are used in everyday life for many purposes:

1. It making electronic components: like, DVD
2. In making paints, plastic bottles and polybags and cables etc.
3. For medical equipment's like medical cup, Heart valves, medical key boards, test tubes and Petri dishes etc.
4. Natural Polymers like cotton, silk, wool and rubber are used for many purposes in daily life.
5. Used for construction purposes to insulate ceiling walls floors etc.
6. Teflon is used to make nonstick cook wares.
7. Nylon is used for textile &fibers
8. Bakelite is a non-conductor so it is used in radioand telephone coating and cables coveringsetc.
9. Plastic is used for packaging or for wrapping materials.
10. In making house hold items like bucket, mug, water bottles, bowls, plates and many more.
11. In making automobiles, furniture and toys.
12. It is used to make ropes that are very strong glues and paints
13. All disposable items, baby products, containers.
14. In agriculture – Irrigation, drainage pipes, fishing nets etc are made up of Plastics
15. For making raincoats, toothbrushes, washing machines and laundry detergents.
16. As fillers to fill cushions and also used in making photographic film.

**Questions for Revision**

1. Chemical processes in which simple molecules are converted into polymers are called ____________.

a) diamerisation b) polymerization c) monomer d) none

2. Monomers of teflon is _________________________.

a) vinyl chloride b) tetrafluroethene c) styrene d) ethene

3. Monomers of PVC is _________________________.

a) vinyl chloride b) tetrafluroethene c) styrene d) ethene

4. PVC is _________________________ polymer.

a) addition b) condensation c) homo d) both a & c

5. Nylon 6,6 is a ____________ polymer.

a) addition b) condensation c) homo d) both a & c

**Short answer questions**

6. Define Polymer.
7. Define monomer.
8. What is degree of Polymerization?
9. What is copolymer?
10. What is homopolymer?
11. Expand PTFE and PVC.
12. Give two uses of low density polymers.
13. Give monomers of Nylon6,6.
14. Give two examples of thermoplastics.
15. Give two examples of Thermosetting Plastic.
16. Give two uses of high density Polymers.
17. Give two examples of Polymers which are formed by addition of different Monomers.
18. What are monomers of Nylon6,6? Give their chemical names.

**Long answer questions**

19. Give Structure of Poly-ethene.
20. How the following polymers prepared? Give chemical reactions involved.

    a) PVC b) Nylon 6,6 c) Bakelite d) Teflon e) PS

**Answers to objective type questions:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | b | 2. | b | 3. | a | 4. | d | 5. | b |