

A Textbook of

APPLIED CHEMISTRY

CH-132

Diploma of Associate Engineer (DAE)



ACADEMIC WING

**TECHNICAL EDUCATION & VOCATIONAL TRAINING AUTHORITY
PUNJAB**

APPLIED CHEMISTRY

CH – 132

For

FIRST YEAR

DIPLOMA OF ASSOCIATE ENGINEER

COMMON WITH:

**Including:
Objective Type
and
Short Questions**

- ❖ **ELECTRICAL**
- ❖ **ELECTRONICS**
- ❖ **COMPUTER**
- ❖ **COMPUTER INFORMATION**
- ❖ **BIOMEDICAL**

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Preface

It is a matter of great pleasure and satisfaction that Academic wing of TEVTA has deemed it fit to prepare a Text Book in the subject of Applied Chemistry (Ch-132) for Electrical, Electronics, computer, computer information and Biomedical technologies. This text book will not only harmonize the contents but it will also serve as a set pattern for the examiner and paper setters. The Text Book under reference will also guide the students in a better way. The contents of the book, after discussion by the committee has been scrutinized, refined & reviewed according to the course outline. The course contents and learning outcomes has been given at the beginning of every Chapter and Exercises has been prepared as per paper pattern of P.B.T.E, Lahore.

It is again a very good omen that TEVTA has decided to publish this book in English version only, as the English is an International language and language of science and technology that will enable the students to meet the problems of market and language. It will also facilitate them for higher studies.

The Manual Development Committee and Manual Evaluation Committee are highly thankful to TEVTA especially GM (ACAD) Engineer Azhar Iqbal Shad and his team for their valuable co-operation and guidance.

May Allah give us courage, patience and spirit of purity for the service of Nation and whole human race.

Ameen

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Chapter 1

Introduction

Course contents	2 Hrs
1.1	The scope and significance of the subject
1.2	Orientation with reference to technology
1.3	Terms used and units of measurements in the study of chemistry

LEARNING OUTCOMES:

After learning this chapter the students would be able to:

- 1.1 Define chemistry and its terms
- 1.2 Define the units of measurements in the study of chemistry
- 1.3 Explain the importance of chemistry in various fields of specialization
- 1.4 Explain the role of chemistry in this technology

INTRODUCTION/ Role of Chemistry in daily life

The word “*chemistry*” is derived from the word “***Kheem***”, which is the old name of Egypt and this name was given due to the black colour of the Egyptian soil. However, some experts believe that it came from the Greek word “***Chyma***” which means ‘melt’ or ‘cast’. The art of *Khemia* flourished in the early Egyptian and Greek civilisations. The word ‘***Khemia***’ then became “***Al-Kimiya***” in Arabic and in English word “***Alchemy***” was later derived.

Chemistry plays an important role in our daily life. Every thing around us like paper, cloth, different articles of plastics, fridge, TV, iron products, fans, heater, etc all owes to chemistry. Chemistry has not only changed the standards of living but has also improved our health condition. We use several chemical products in our daily life for cooking, cleaning, personal hygiene, detergents, insecticides, paints, drugs etc. Surgical procedures are carried out with the help of chemicals like anaesthetics etc. Several artificial items like nylon, plastics, dyes etc have been prepared with the help of chemistry.

Similarly many explosives and chemical weapons used in the warfare are the products of chemistry. Artificial fertilisers have increased our productivity many folds. Moreover many metals are being extracted with the help of chemistry. Simply there is hardly any field of our daily life where chemistry is not playing a dominant role for the betterment of mankind. This chapter is of basic nature that focuses on mainly basics, that empowers the learner to over come chemistry.

Chemistry:

‘Chemistry is that branch of science that deals with the study of properties, composition and structure of matter, along with the changes in structure, composition and energy that the matter undergoes’. It also deals with the laws and principles, which govern these changes. Or simply the study of nature of the matter is called ***chemistry***.

ROLE OF CHEMISTRY IN DIFFERENT TECHNOLOGIES:-

Technology is the practical form of the chemistry as chemistry devise rules while technology provides us the instruments and means to execute these rules. Chemistry is equally important in all technologies, for example;

1. Chemistry and Electrical Technology:

Electrical technology deals with the electrification and related instruments of all walks of life. All the electrification accessories like wires, pipes, plates, switches etc are manufactured with the help of chemistry. It is an admitted fact that the electricity is one of our poor servants and it is only possible with the help of chemistry.

Similarly the flow of electrons is called current. It is impossible to study current and electricity and its use for human benefits without knowing the structure of matter, which is impossible without the knowledge of chemistry. To understand the concept and use of conductors, insulators, semiconductors, electrolytes, non-electrolytes is inevitable without chemistry. Electrolysis, electroplating, electro-metallurgy and the production of electricity from coal, furnace oil, solar cell, the lead storage battery and atomic fuel (Uranium) etc are the excellences of chemistry.

Similarly the instruments used in electrical technology like tester, voltmeter etc, and the material used for recreation and better living like refrigerators, microwave, AC, etc are prepared with the help of chemistry. Moreover Freon gas that is used in refrigerators and air conditioners, etc are the blessings of chemistry. In short the electrical technology will just be rubbish without the knowledge of chemistry.

2. Chemistry and Electronics, & Computer, Computer Information Technologies:

The concept of conductors and semiconductors is better understood in this technology because the development and use of Silicon and Germanium as semiconductors has revolutionised the electronic industry. Moreover all the electronic circuits that are made on the Bakelite plate are prepared by the ‘etching process’ – a chemical reaction. A number of electronic instruments like radio, TV, VCR, VCD, DVD, cellular phones, satellite system, wireless

communication etc has gained a tremendous popularity in these days, and it is only because of chemistry.

Similarly the flow of electrons is called current. It is impossible to study current and electricity and its use for human benefits without knowing the structure of matter, which is impossible without the knowledge of chemistry. To understand the concept and use of conductors, insulators, semiconductors, electrolytes, non-electrolytes is inevitable without chemistry. Electrolysis, electroplating, electro-metallurgy and the production of electricity from coal, furnace oil, solar cell, the lead storage battery and atomic fuel (Uranium) etc are the excellences of chemistry.

Similarly the instruments used like tester, volt-meter, multi-tester, avo-meter etc, and the material used for recreation and better living like refrigerators, microwave, AC, etc are prepared with the help of chemistry. More over Freon gas that is used in refrigerators and air conditioners, etc are the blessings of chemistry.

UNITS OF MEASUREMENTS:

The quantity of a substance that describes its parameters and admitted internationally is called unit. Chemistry deals with the several kinds of measurements. Accurate measurements of minute quantities of reactants and products are involved in it. All measurements are based on a system of units. A measurement is a number that describes the amount of some thing.

There are four systems of measurements in chemistry for quantitative aspects i.e.,

- | | |
|---------------|-----------------|
| 1. CGS system | 2. MKS system |
| 3. S.I system | 4. F.P.S system |

S.I system:

Nowadays a system has been adopted at the international level known as S.I system – from French words “*Le Systeme Internationale d'Unites*”

means that '*International System of Units*'. This system was adopted in 1964 after combining CGS, MKS etc systems. It includes both basic as well as derived units.

S.I basic or fundamental units:

The S.I system is based upon seven physical quantities and their units are considered as basic or fundamental units. These are:

S.#	Physical quantity	Name of the unit	Symbol of unit
1.	Length	Metre	m
2.	Mass	Kilogram	Kg
3.	Temperature	Kelvin	K
4.	Time	Second	sec or s
5.	Amount of a substance	Mole	mol
6.	Electric current	Ampere	A
7.	Light intensity	Candela	Cd

A brief detail of each one is given below:

1. Metre (m):

The distance between two points is called length and metre is the unit of length. It is defined as the distance between the two points marked on a Platinum-Irridium alloy rod or bar placed at Sevres in Paris. Or it is the distance that light travels in 3×10^{-8} seconds. Its other parameters are:

S.#	Unit	Symbol	Meter equivalent	Exponents
1.	Kilometre	Km	1000 m	10^3 m
2.	Decimetre	dm	0.1 m	10^{-1} m
3.	Centimetre	cm	0.01 m	10^{-2} m
4.	Millimetre	mm	0.001 m	10^{-3} m
5.	Micrometer	μm	0.000001 m	10^{-6} m

2. Kilogram (Kg):

The quantity of matter in a body is called mass and the unit of mass is kilogram. It is defined as the mass of a solid cylinder of Platinum-Irridium

alloy placed at International Bureau of Weight and Measure at Sevres in Paris.

The other units of mass are given below:

S.#	Unit	Symbol	Gram equivalent	Exponents
1.	Kilogram	Kg	1000 g	10^3 g
2.	Gram	g	1 g	10^0 g
3.	Decigram	dg	0.1 g	10^{-1} g
4.	Centigram	cg	0.01 g	10^{-2} g
5.	Milligram	mg	0.001 g	10^{-3} g
6.	Microgram	μ g	0.000001 g	10^{-6} g

3. Second (sec):

The interval between two happenings is called time and the unit of time is second. “A second is the $\frac{1}{86400}^{\text{th}}$ part of the solar day.” Or “it is the time required to complete 91,922,631 cycles of a Cesium ray in vacuum”.

$$\begin{array}{lll} 1 \text{ minute} & = & 60 \text{ seconds} \\ 1 \text{ hour} & = & 60 \text{ minutes} \\ 1 \text{ solar day} & = & 24 \text{ hours} \\ 1 \text{ year} & = & 365\frac{1}{4} \text{ solar days.} \end{array}$$

4. Kelvin (K):

The average kinetic energy of a substance is called temperature and it measures the hotness or coldness of a substance. The unit of temperature is Kelvin. It is also called absolute scale. Absolute zero or -273°C is the lowest temperature possible and is written as ‘0K’ – zero Kelvin. The other units for the measurement of temperature are Centigrade ($^{\circ}\text{C}$) or Celsius scale and Fahrenheit ($^{\circ}\text{F}$). These are related with each other as follows:

$$0^{\circ}\text{C} \cong 273\text{K} \cong 32^{\circ}\text{F}$$

These three scales of temperature can be inter-converted with each other by the following relations:

$$\begin{array}{lll} \text{K} & = & {}^{\circ}\text{C} + 273 \\ {}^{\circ}\text{F} & = & [1.8 \times {}^{\circ}\text{C}] + 32 \end{array}$$

$$^{\circ}\text{C} = \frac{^{\circ}\text{F} - 32}{1.8}$$

5. Mole (mol):

The unit of amount of a substance is called *mole*. The atomic weight, molecular weight or ionic weight of a substance expressed in grams is called *mole*. For example

1 mol of oxygen	=	32 g
1 mol of hydrogen	=	2 g
1 mol of water	=	18 g etc.

6. Ampere (A):

The unit of electric current is called ampere. It is defined as the passage of 6.28×10^{18} electrons through a conductor in one second is called an *ampere*. Or it is the amount of current flowing through a resistance of 1 ohm that has a potential difference of 1 volt across it. Mathematically

$$I = \frac{V}{R}$$

Where I = electric current, V = volts, & R = resistance in ohms.

7. Candela (Cd):

The unit of intensity of light is called candela. It is defined as the intensity of light falling perpendicularly on a black body of area $\frac{1}{600000} \text{ m}^2$ at the temperature of freezing platinum at 760mmHg.

DERIVED UNITS:

Units of those physical quantities that can be derived from the basic units are called derived units. For example units of volume, density etc is a derived unit. These are explained below:

1. Volume (V):

The space occupied by a body is called *volume*. Its unit is Cubic-metre (m^3). So

$$V = L \times W \times H$$

Where L= length, W = width & H = height. Its other units are:

1 dm ³	=	0.1 m ³
1 cm ³	=	0.01 m ³
1 cm ³	=	1 mL
1 dm ³	=	1 L

2. Density (d):

The mass per unit volume of a substance is called *density*.

Mathematically

$$d = \frac{m}{v}$$

Where d = density, m = mass of the body, v = volume of the body. Its units are Kilogram per metre cube (Kg/m³), gram per centimetre cube (g/cm³) & gram per millilitre (g/mL).

3. Specific gravity:

The specific gravity of a substance is the ratio of its mass to the mass of equal volume of water at 4°C and thus has no unit.

$$\text{Specific gravity} = \frac{\text{Mass of the substance}}{\text{Mass of equal volume of water}}$$

OR

The specific gravity of a substance is the ratio of its density to the density of water.

$$\text{Specific gravity} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

4. Pressure (P):

The force acting on a unit area is called *pressure*. Mathematically

$$P = \frac{F}{A}$$

Where P = pressure, F = force & A = area. Its units are Pascal (Pa), mm of Hg or N/m² (Newton per meter square).

5. Force (F):

The unit of force is Newton (N), which is defined as the force that needed to accelerate body of 1 Kg at the rate of one metre per second squared.
1 N = 1Kg.m/s².

6. Quantity of Electricity:

The derived unit of quantity of electricity is the Coulomb (C). If a current of 1-ampere flows through a conductor for 1 second is known as *Coulomb*.

$$C = I \times \text{sec}$$

Where C = Coulomb, I = ampere and sec = second

STANDARD UNIT:

A standard unit is one whose size is internationally agreed. It may be basic or derived. For example kilogram is the standard unit of mass.

OBJECTIVE QUESTIONS

Q. Give answer to the following short questions:

1. Define chemistry.
2. What is the relation between chemistry and technology?
3. Define Candela.
4. Define basic and derived units.
5. Define meter and second.
6. Define the unit of temperature in S.I system.
7. Define volume and specific gravity.
8. Define density and also give its units.

9. Define pressure and give its units.
10. The unit 'coulomb' belongs to which physical quantity?
11. What is meant by standard unit?
12. Give the role of chemistry in our daily life.

Q. Select the correct answer from the following**MCQ's.**

1. The study of the nature of the matter is called
 - (a) Biology
 - (b) Technology
 - (c) Chemistry
 - (d) Physics
2. The word 'Chyma' means
 - (a) To heat
 - (b) melt or mould
 - (c) bending
 - (d) freezing
3. The practical form of technology is called
 - (a) Chemistry
 - (b) Physics
 - (c) Biology
 - (d) Maths
4. Technology is concerned with the transmission of electricity and its allied instruments
 - (a) Electrical
 - (b) Mechanical
 - (c) Instrument
 - (d) Civil
5. Ais one whose size is internationally agreed.
 - (a) mole
 - (b) standard unit
 - (c) atom
 - (d) molecule
6. There are systems of units of measurement in fore in the world
 - (a) 3
 - (b) 4
 - (c) 2
 - (d) 1
7. The unit of length in S.I system is

LONG QUESTIONS

- Q. Define chemistry. Explain its role in our daily life.
Q. Describe the role of chemistry in your technology.
Q. What are basic and derived units?
Q. Define the following:
Volume, ampere, density, second, Kg,
mole, metre, temperature.



Chapter 2

Fundamental concepts of Chemistry

Course contents	2 Hrs
2.1 Symbol, valency, radical, formula	
2.2 Chemical reactions and their types	
2.3 Balancing of equations by ionic method	

LEARNING OUTCOMES:

After learning this chapter the students would be able to:

- 2.1 Define symbol, valency, radical, formula with examples of each
- 2.2 Write chemical formula of some common compounds
- 2.3 Define chemical reaction and equation
- 2.4 Describe the types of chemical reactions with examples
- 2.5 Explain the methods of balancing of equations by ionic method

INTRODUCTION:

This chapter basically relates to understand the terms of chemistry that empowers a learner to understand the core concepts of chemistry. It includes basic terms used in chemistry along with types of chemical reactions.

TERMS USED IN CHEMISTRY**1. Matter:**

Matter is the stuff by which the universe is made. So any thing that carries mass and occupies space is called *matter*. For example book, water etc.

States of matter:

Following are the three states of matter;

i. Solid state:

The substances having definite shape and definite volume are called *solids*. Solids retain their shape everywhere and have compact structure. For example book, stone, wood etc.

ii. Liquid state:

The substances having definite volume but no definite shape are called *liquids*. These change their shape as to the shape of the container and have loose structure. For example oil, water etc.

iii. Gaseous state:

The substances having neither definite shape nor volume are called *gaseous* state. These can spread to a vast area and have very loose structure. For example air, oxygen, nitrogen etc.

2. Element:

The purest form of matter is called element. A substance that cannot be further divided into simpler substances by physical or chemical means is called an *element*. Or that type of matter that consists of identical atoms having same atomic number is called *element*.

At present 111 elements has been discovered, out of which 92 are natural occurring and rest are man made. Elements are available in all the three physical states of matter like hydrogen, oxygen, nitrogen etc are gases and bromine, mercury etc are liquids while iron, copper, sodium, magnesium, carbon, sulphur etc are solids.

3. Compound:

A substance produced by the chemical combination of two or more elements is called a *compound*. Or a substance containing two or more elements combined together in a fixed ratio by mass.

A compound is always formed as a result of chemical change and its properties are quite different than the original atoms. For example water, carbon dioxide, table salt etc.

4. Mixture:

When two or more elements or compounds are mixed together so that no chemical reaction takes place between them is called a *mixture*. Or it is the impure form of matter consisting of different kinds of elements or compounds. A mixture can easily be separated by physical methods. For example flour, mixture of sand and salt, brass etc. There are two kinds of mixtures i.e.,

i. Homogeneous mixture:

It is the mixture having through out uniform composition. These are also called solutions. For example milk, salt solution etc.

ii. Heterogeneous mixture:

It is the mixture having through out different composition. For example ice cream, soil, rock etc.

5. Atom:

Atom is the smallest particle of the element that may or may not exist alone and takes part in a chemical reaction. Or it is the smallest particle of an element that shows all its properties. Atoms of one element are generally similar to each other and differ from the atoms of other elements. It contains only one nucleus. For example C, Na, O, H etc are atoms.

6. Molecule:

It is the smallest particle of the matter and is capable of free existence in nature and may undergo subdivisions in a chemical reaction. It is usually formed by the combination of two or more similar or different atoms. It usually consists of more than one nucleus. For example HCl, H₂O, O₂, CO₂ etc are molecules.

7. Physical change:

Such a change in which no new product is formed is called *physical change*. The substances may undergo a change in physical state. These changes are temporary in nature. Usually mixtures are formed as a result of physical change. For example melting of ice, wax etc.

8. Chemical change:

Such a change in which a new product is formed is called *chemical change*. Usually compounds are formed as a result of chemical change. These changes are permanent in nature. For example respiration, rusting of iron, burning of wood & wax etc.

9. Ion:

An atom or group of atoms carrying a charge is called an *ion*. It may be positive or negative. The positive ion is called '*cation*' while a negative ion is called '*anion*'. These can exist only in the solution. For example H^+ , O^{-2} , and Cl^- etc.

10. Radical:

An atom or group of atoms carrying a charge that takes part in a chemical reaction and behaves as an entity is called a *radical*. These are formed by loosing or gaining electrons. These may be simple like H^+ , O^{-2} , Cl^- or compound like NO_3^- , NH_4^+ etc. So all the ions may be called radicals but all the radicals may not be called ions.

Simple radical:

The radical that contains single element is called simple radical. For example Cl^- , Br^- , O^{-2} etc are simple negative radicals while H^+ , Na^+ , Mg^{++} etc are simple positive radicals.

Compound radicals:

Such radicals that are formed by the combination of more than one element are called compound radicals. For example CO_3^{-2} , SO_4^{-2} , HCO_3^{-1} ,

PO_4^{-3} , NO_3^{-1} etc are the examples of negative compound radicals while NH_4^{+1} is the example of positive compound radical.

11. Symbol:

It is the abbreviated name of an element and written in place of whole name of the element. A symbol is the first letter or the 1st and 2nd or another characteristic letter of English, Latin or Greek. A symbol represents one atom of the element. Symbols are written by the following rules:

1. These are composed of one or two letters.
2. If one letter is used it is written in capital words.
3. If two letters are used the 1st is the upper case and 2nd is the lower case.

Some of the symbols are given below:

S Y M B O L S

One Alphabet symbol		Two alphabet symbol	
Element	Symbol	Element	Symbol
Boron	B	Helium	He
Nitrogen	N	Bromine	Br
Fluorine	F	Calcium	Ca
Sulphur	S	Magnesium	Mg
Uranium	U	Zinc	Zn
Carbon	C	Aluminium	Al
Oxygen	O	Barium	Ba
Phosphorus	P	Cobalt	Co
Iodine	I	Manganese	Mn
Vanadium	V	Chlorine	Cl
Hydrogen	H	Silicon	Si

Symbols consisting alphabets taken from the Latin, or Greek are given below:

Latin / Greek symbols			
S.#	English name	Latin/Greek name	Symbol
1.	Potassium	Kalium	K
2.	Iron	Ferrum	Fe
3.	Copper	Cuprum	Cu
4.	Silver	Argentum	Ag
5.	Tin	Stannum	Sn
6.	Antimony	Stibium	Sb
7.	Tungsten	Wolfrom	W
8.	Gold	Aurum	Au
9.	Mercury	Hydrargyrum	Hg
10.	Lead	Plumbum	Pb
11.	Sodium	Natrium	Na

12. Valency:

The combining capacity of an element is called *valency*. Or the capacity of elements to loose or gain electrons in a chemical reaction to complete their outer most octet is called *valency*. Or it is the number of electrons present in the outer most shell of an atom that takes part in the bond formation. Or the number of hydrogen atoms that can combine with an element, then it will be called *valency* of that atom.

The valency may be positive or negative. If an atom loses an electron it form positive valency and if it gain electron it form negative valency. The elements having valency ‘1’ are called *monovalent*, ‘2’ are called *divalent*, ‘3’ are called *trivalent*, ‘4’ are called *tetravalent*. For example the valency of hydrogen and chlorine is ‘1’, oxygen ‘2’, and nitrogen ‘3’ etc.

Variable valency:

The elements having more than one valency is called variable valency. The lower valency of the element is written with the ending name ‘-ous’ like Fe^{++} – ferrous and higher valency with ‘-ic’ like Fe^{+++} – ferric. Some elements

show multiple variable valencies like Manganese show +2, +4, +6, & +7 valency. The valency chart of various elements is given below

MONOVALENT RADICALS

Monovalent cations(+)		Monovalent anions(-)	
Radical	Formula	Radical	Formula
Hydrogen	H ⁺	Chloride	Cl ⁻
Sodium	Na ⁺	Bromide	Br ⁻
Potassium	K ⁺	Flouride	F ⁻
Silver	Ag ⁺	Nitrite	NO ₂ ⁻
Cuprous	Cu ⁺	Nitrate	NO ₃ ⁻
Ammonium	NH ₄ ⁺	Bicarbonate	HCO ₃ ⁻
Lithium	Li ⁺	Bisulphate	HSO ₄ ⁻
Mercurous	Hg ⁺	Hydride	H ⁻
Cesium	Cs ⁺	Hydroxide	OH ⁻
Francium	Fr ⁺	Accetate	CH ₃ COO ⁻

DIVALENT RADICALS

Divalent cations(+)		Divalent anions(-)	
Radical	Formula	Radical	Formula

Cupric	Cu^{++}	Sulphide	S^{-2}
Calcium	Ca^{++}	Sulphite	SO_3^{-2}
Strontium	Sr^{++}	Sulphate	SO_4^{-2}
Barium	Ba^{++}	Thiosulphate	$\text{S}_2\text{O}_3^{-2}$
Magnesium	Mg^{++}	Carbonate	CO_3^{-2}
Manganese	Mn^{++}	Manganate	MnO_4^{-2}
Zinc	Zn^{++}	Chromate	CrO_4^{-2}
Cadmium	Cd^{++}	Dichromate	$\text{Cr}_2\text{O}_7^{-2}$
Mercuric	Hg^{++}	Peroxide	O_2^{-2}
Stannous	Sn^{++}	Oxide	O^{-2}
Plumbous	Pb^{++}	Zincate	ZnO_2^{-2}
Ferrous	Fe^{++}	Stannate	SnO_3^{-2}
Cobalt	Co^{++}	Silicate	SiO_3^{-2}
Nickel	Ni^{++}	Oxalate	$\text{C}_2\text{O}_4^{-2}$

TRIVALENT RADICALS

Trivalent cations(+)		Trivalent anions(-)	
Radical	Formula	Radical	Formula
Ferric	Fe^{+++}	Nitride	N^{-3}
Aluminium	Al^{+++}	Phosphide	P^{-3}
Aurum	Au^{+++}	Phosphate	PO_3^{-3}
Chromium	Cr^{+++}	Borate	PO_4^{-3}
Bismuth	Bi^{+++}	Ferricyanide	$[\text{Fe}(\text{CN})_6]^{-3}$
Boron	B^{+++}		

TETRAVALENT RADICALS

Tetraivalent cations(+)		Tetraivalent anions(-)	
Radical	Formula	Radical	Formula
Stannic	Sn^{++++}	Carbide	C^{-4}
Plumbic	Pb^{++++}	Ferrocyanide	$[\text{Fe}(\text{CN})_6]^{-3}$
Silicon	Si^{++++}		
Germanium	Ge^{++++}		

13. Formula:

The symbolic representation of one molecule of a compound is called *formula*. It is composed of symbols of elements present in one molecule of a compound. A chemical formula shows the chemical composition as well as the mass ratio in which the atoms are combined. It also indicates the valency of combining elements or radicals. For example the formula of water is H_2O , etc.

Following are the three types of formulae:

i. Simple or empirical formula:

It is the formula that shows the simplest ratio of elements present in one molecule of a compound. For example CH_2 , and CH_2O are the empirical formula of benzene and glucose respectively.

ii. Molecular formula:

It is the formula that shows the exact number of atoms of different elements present in one molecule of a compound. For example C_6H_6 and $\text{C}_6\text{H}_{12}\text{O}_6$ are the molecular formula of benzene and glucose respectively.

iii. Structural formula:

It is the formula that shows the exact arrangement and bonding of atoms of different elements present in one molecule of a compound. For

example $O = C = O$ and $H - O - H$ are the structural formula of CO_2 and H_2O respectively.

The formulas of some common compounds are given below:

S.#	Name of the compound	Formula
1.	Ferrous sulphate	$FeSO_4$
2.	Calcium phosphate	$Ca_3(PO_4)_2$
3.	Calcium hydroxide(Slaked Lime)	$Ca(OH)_2$
4.	Calcium oxychloride(Bleaching powder)	$CaOCl_2$
5.	Methane(Major portion of Sui gas)	CH_4
6.	Potassium dichromate	$K_2Cr_2O_7$
7.	Potassium permanganate (Pinky)	$KMnO_4$
8.	Potassium hydroxide (Caustic potash)	KOH
9.	Potassium chlorate	$KClO_3$
10.	Sodium thiosulphate (Hypo)	$Na_2S_2O_3$
11.	Sodium phosphate	Na_3PO_4
12.	Sodium chloride(Table salt)	$NaCl$
13.	Ammonium chloride (Naushader)	NH_4Cl
14.	Ammonium hydroxide	NH_4OH
15.	Ammonia	NH_3
16.	Aluminium sulphate	$Al_2(SO_4)_3$
17.	Ferrous sulphide	FeS
18.	Calcium carbonate (Lime stone)	$CaCO_3$
19.	Calcium oxide (Un slaked Lime)	CaO
20.	Phosphoric acid	H_3PO_4
21.	Hydrochloric acid	HCl
22.	Nitric acid	HNO_3
23.	Sulphuric acid	H_2SO_4

24.	Zinc sulphate	ZnSO_4
25.	Lead nitrate	$\text{Pb}(\text{NO}_3)_2$
26.	Silver nitrate	AgNO_3
27.	Sodium hydroxide (Caustic soda)	NaOH
28.	Sodium carbonate (Washing soda)	Na_2CO_3
29.	Sodium bicarbonate(Baking soda)	NaHCO_3
30.	Acetic acid (Vinegar)	CH_3COOH

Acid radicals		Chloride Cl^{-1}	Hydroxide OH^{-1}	Nitrate NO_3^{-1}	Carbonate CO_3^{-2}	Sulphate SO_4^{-2}
Basic radicals						
Hydrogen	H^{+1}	HCl	HOH	HNO_3	H_2CO_3	H_2SO_4
Sodium	Na^{+1}	NaCl	NaOH	NaNO_3	Na_2CO_3	Na_2SO_4
Silver	Ag^{+1}	AgCl	AgOH	AgNO_3	Ag_2CO_3	Ag_2SO_4
Ammonium	NH_4^{+1}	NH_4Cl	NH_4OH	NH_4NO_3	$(\text{NH}_4)_2\text{CO}_3$	$(\text{NH}_4)_2\text{SO}_4$
Magnesium	Mg^{+2}	MgCl_2	Mg(OH)_2	$\text{Mg(NO}_3)_2$	MgCO_3	MgSO_4
Ferrous	Fe^{+2}	FeCl_2	Fe(OH)_2	$\text{Fe(NO}_3)_2$	FeCO_3	FeSO_4
Ferric	Fe^{+3}	FeCl_3	Fe(OH)_3	$\text{Fe(NO}_3)_3$	$\text{Fe}_2(\text{CO}_3)_3$	$\text{Fe}_2(\text{SO}_4)_3$
Cupric	Cu^{+2}	CuCl_2	Cu(OH)_2	$\text{Cu(NO}_3)_2$	CuCO_3	CuSO_4
Mercuric	Hg^{+2}	HgCl_2	Hg(OH)_2	$\text{Hg(NO}_3)_2$	HgCO_3	HgSO_4
Stannous	Sn^{+2}	SnCl_2	Sn(OH)_2	$\text{Sn(NO}_3)_2$	SnCO_3	SnSO_4
Stannic	Sn^{+4}	SnCl_4	Sn(OH)_4	$\text{Sn(NO}_3)_4$	$\text{Sn}_2(\text{CO}_3)_4$	$\text{Sn}_2(\text{SO}_4)_4$
Calcium	Ca^{+2}	CaCl_2	Ca(OH)_2	$\text{Ca(NO}_3)_2$	CaCO_3	CaSO_4
Barium	Ba^{+2}	BaCl_2	Ba(OH)_2	$\text{Ba(NO}_3)_2$	BaCO_3	BaSO_4
Zinc	Zn^{+2}	ZnCl_2	Zn(OH)_2	$\text{Zn(NO}_3)_2$	ZnCO_3	ZnSO_4
Aluminium	Al^{+3}	AlCl_3	Al(OH)_3	$\text{Al(NO}_3)_3$	$\text{Al}_2(\text{CO}_3)_3$	$\text{Al}_2(\text{SO}_4)_3$
Plumbous	Pb^{+2}	PbCl_2	Pb(OH)_2	$\text{Pb(NO}_3)_2$	PbCO_3	PbSO_4
Plumbic	Pb^{+4}	PbCl_4	Pb(OH)_4	$\text{Pb(NO}_3)_4$	$\text{Pb}_2(\text{CO}_3)_4$	$\text{Pb}_2(\text{SO}_4)_4$
Sugar	$\text{C}_{12}\text{H}_{22}\text{O}_6$					
Glucose	$\text{C}_6\text{H}_{12}\text{O}_6$					
Soap	$\text{C}_{17}\text{H}_{35}\text{COONa}$					

14. Atomic number:

It is also called proton number. It is the number of electrons or protons present in one atom of an element. Or it is the number of unit positive charges contained in the nucleus of an element. This number is unique for every element. More over the periodic table is based on the atomic number. It

is represented by “Z”. For example the atomic number of hydrogen, carbon and oxygen is 1, 6 & 8 respectively.

15. Atomic mass or weight:

It is also called nucleon number. The mass of an atom is approximately equal to the total mass of all its sub atomic particles. It is the average mass of an element as compared to the relative atomic mass of the carbon taken as 12. It is represented by “A”. Its unit is ‘a.m.u’ or the atomic mass unit. For example the atomic mass of hydrogen, nitrogen and oxygen is 2, 14 & 16 respectively.

Gram atomic mass:

The atomic mass of a substance expressed in grams is called ‘gram atomic mass’. It is also called gram atom. For example 1-gram atom of Carbon and Sodium is 12 & 23 gm respectively.

16. Molecular weight or mass:

It is the sum of the atomic masses of all the atoms of different elements present in one molecule of a compound. It is also expressed in a.m.u. For example the molecular mass of water and CO₂ is 18 & 44 respectively.

Gram molecular mass:

It is the molecular mass of a substance expressed in grams. It is also called ‘gram mole’. For example 1-gram mole of water and glucose is equal to 18 & 180 gm respectively.

17. Avogadro’s number:

It is the number of ions, atoms or molecules present in one mole of a substance. It is represented by “N” and it has a constant value of 6.02×10^{23} . For example 1-mole of Na metal contains 6.02×10^{23} atoms and 1-mole of CO₂ contains 6.02×10^{23} molecules.

18. Mole:

The atomic mass, formula mass or molecular mass of a substance expressed in grams is called '*mole*'. For example one mole of Na metal and water is equal to 23 & 18 grams respectively.

19. Atomicity:

It is the number of atoms present in one molecule of an element. For example the atomicity of sodium (Na), hydrogen (H₂), oxygen (O₂), ozone (O₃) and sulphur (S₈) is 1, 2, 2, 3 & 8 respectively. These are also called mono-atomic, di-atomic, tri-atomic etc.

20. Atomic mass unit: (amu)

It is abbreviated as amu. The atomic mass of carbon is 12 and the value of 1/12 is the atomic mass unit. The atomic mass of other elements is determined by comparing their masses with amu.

$$1 \text{ amu} = \frac{1}{12} = 1.66 \times 10^{-24} \text{ g}$$

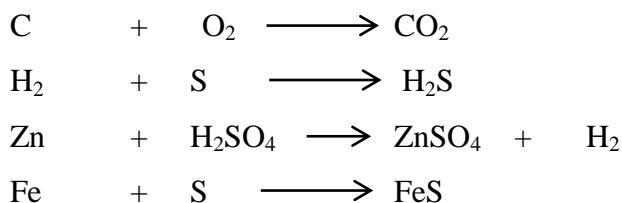
Equation:

An equation or chemical equation is the condensed short hand statement that expresses a chemical reaction in terms of symbols and formula of the elements and compounds involved. Or simply the short hand notation of a chemical reaction is called '*equation*'. Following are the steps involved in writing up the chemical equations:

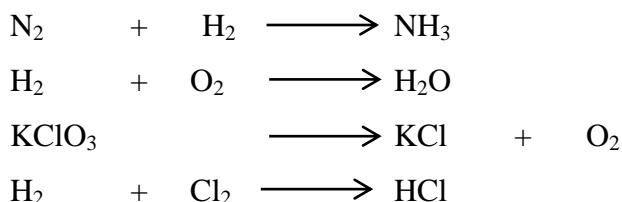
1. The reactants are written on the left-hand side.
2. The products are written on the right-hand side.
3. An arrow pointing from reactants to products is placed in between them.
4. Sometimes the conditions of the reaction like temperature, pressure are written above or below the arrow and physical state of the reactants or products are also given.

Balanced equation:

A balanced equation is such an equation that has same number of atoms on both sides of the reactants and products. For example

**Unbalanced equation:**

An unbalanced equation is such an equation that has different number of atoms on both sides of the reactants and products. For example

**CHEMICAL REACTION:**

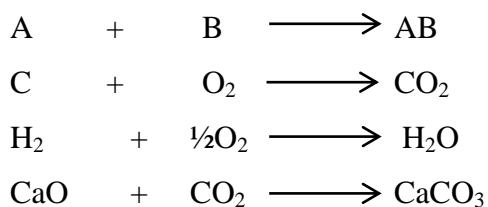
A chemical reaction results when two or more elements or compounds react with each other, or a compound breaks up to give two or more substances. Or such processes that bring about a change in the chemical composition of one or more substances are called *chemical reaction* or simply reaction. The composition of substances changes as a result of chemical reaction and new products are formed. For example the burning of carbon in air to form CO_2 . Most of the chemical reactions are permanent in nature i.e. these are irreversible. However few reactions may be reversible.

Types of chemical reactions:

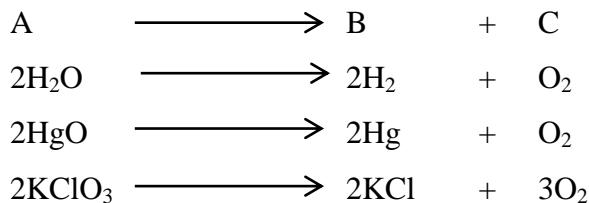
Following are the six major types of reactions;

1. Synthesis or addition reaction:

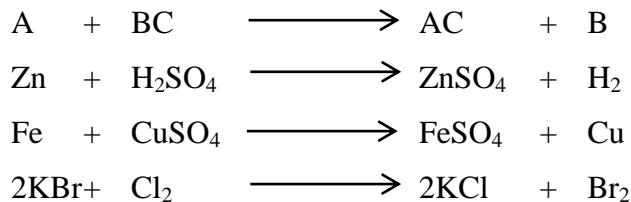
In this reaction two or more substances, elements or compounds combine together to form a more complex substance. For example

**2. Decomposition reaction:**

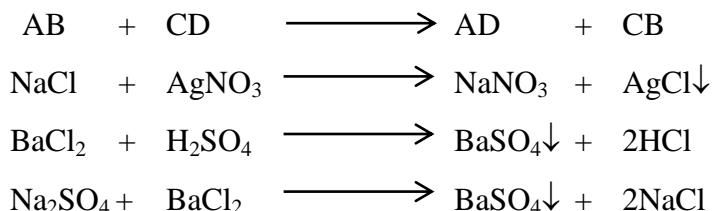
In this reaction a substance is broken down into two or more simpler substances. For example

**3. Displacement reaction:**

In this reaction an atom or group of atoms displaces another atom or group of atoms from a molecule. For example

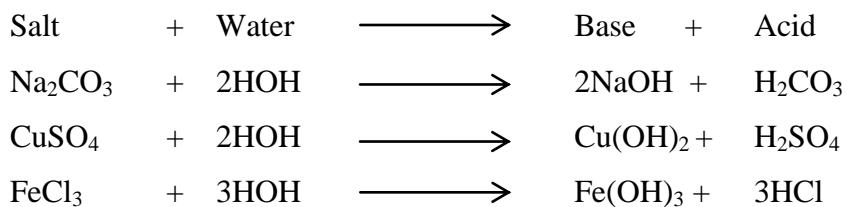
**4. Double displacement reaction:**

In this chemical reaction two reacting molecules exchange their partners to form new products. This type of reaction is also termed as '*metathesis*'. For example

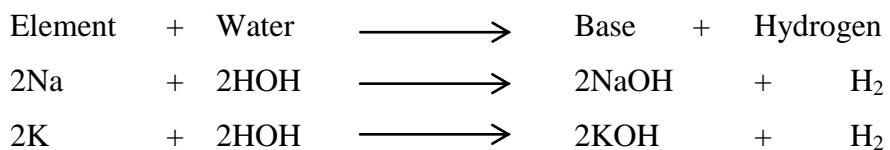


5. Hydrolysis reaction:

In this type of reaction one of the reactant must be water. It results in the cleavage of H–OH bond. If a salt reacts with water, then it results in the formation of corresponding acid and base. For example

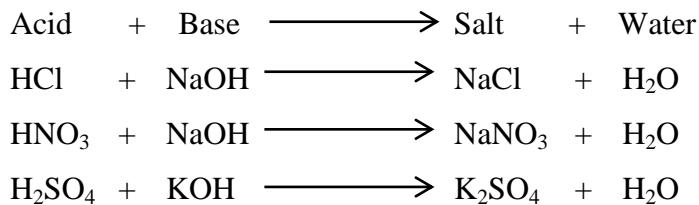


However if an element reacts with water, then it results in the formation of corresponding base and hydrogen gas. For example



6. Neutralisation reaction:

In this reaction the reactants must be an acid as well as a base. These neutralise the properties of each other to form salt and water. For example



Balancing of chemical equation:

A balance equation carries equal number of atoms or molecules on both sides of the equation otherwise it will be an unbalanced equation. Following are the methods available for the balancing of a chemical equation:

1. Hit and trial method
2. Oxidation number method
3. Ion electron or ionic method
4. Partial equation method

Simply the equations are balanced by placing a number on either side of the equation as the formulas of the compounds are fixed and so cannot be changed.

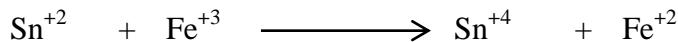
Ion electron or ionic method:

Following are the rules to balance an equation by this method:

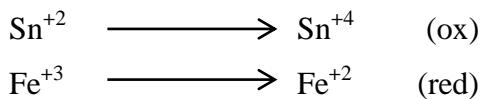
1. Write the unbalanced equation in ionic form.
2. Divide the given equation in to two half reactions i.e oxidation half reaction and reduction half reaction.
3. Add H^+ , OH^- or H_2O to both sides of the half reactions if necessary.
4. Balance both of the half reactions with respect to atoms.
5. Balance both of the half reactions with respect to electrons.
6. If the number of electrons released in oxidation half reaction is not equal to electrons required in reduction half reaction, multiply both of the half reactions with suitable numbers to make them equal.
7. Add both of the half equations.
8. If same items are present on both sides of the equation, cut them with suitable method.
9. Check the equation balance with respect to atoms and charge.

Example – 1:

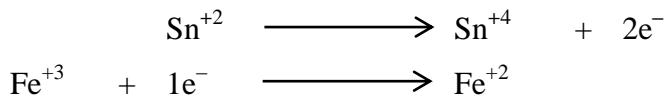
Balance the equation by the ionic method:



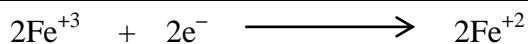
According to rule – 2:



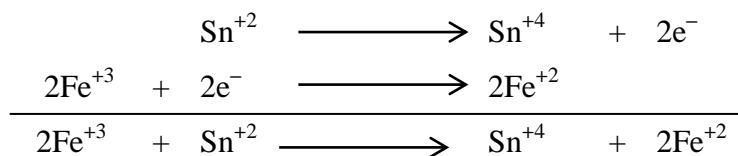
According to rule – 5:



According to rule – 6, multiply 2nd equation by 2:



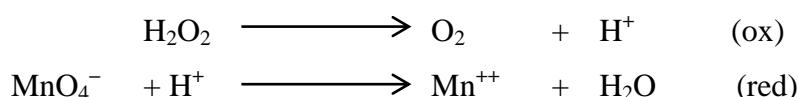
According to rule – 7:



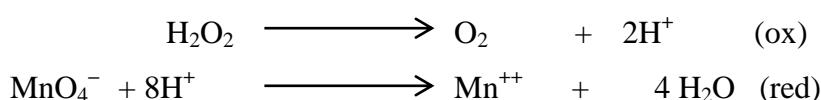
Example – 2:



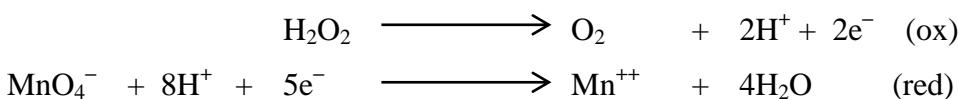
According to rule – 2:



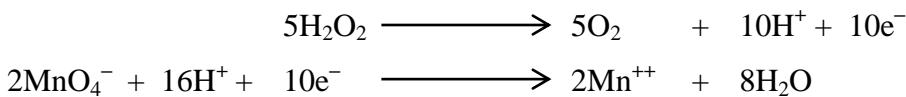
According to rule – 4:



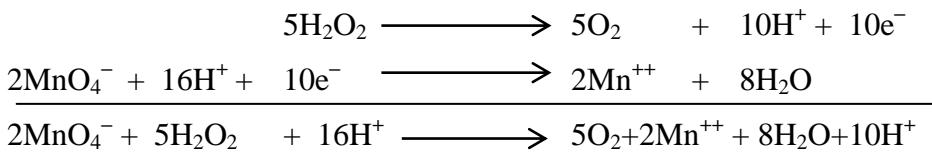
According to rule – 5:



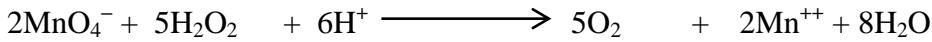
According to rule – 6, multiply 1st equation by 5 and 2nd by 2,



According to rule – 7:

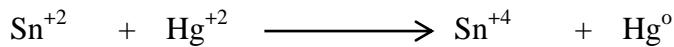


According to rule – 8

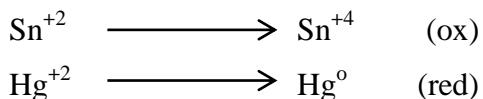


Example – 3:

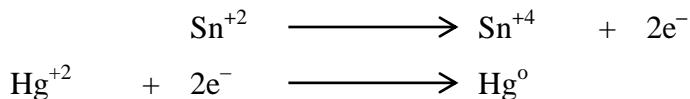
Balance the equation by the ionic method:



According to rule – 2:

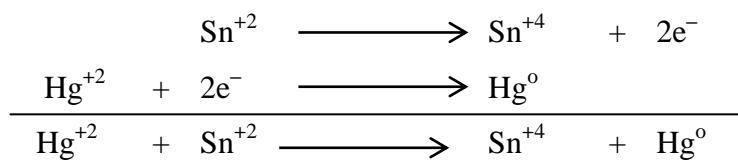


According to rule – 5:



According to rule – 6, as the number of electrons are equal so there is no need to multiply any equation by any number:

According to rule – 7:



OBJECTIVE QUESTIONS

Q. Give answer to the following short questions:

1. Define Mole.
2. Define atom and molecule.
3. Define cation and anion
4. Define gram atom and gram molecule.
5. Describe Radial.
6. Define variable valency
7. Define formula and enlist its any two types.
8. Define chemical equation and give an example.
9. Write down the name of methods to balance a chemical equation.
10. Why water is necessary in the 'Hydrolysis reaction'?
11. Define Avogadro number and give its value.

12. What is the difference between simple and compound radical?

Q. Select the correct answer from the following MCQ's.

1. The purest form of matter is called

2. The smallest particle of an element that shows all its properties is called

3. The positive ion is called

4. The combining capacity of an element is called

5. The valency of sodium ion is

6. The abbreviated name of an element is called

7. Which one is a radical?

8. The molecular mass of sulphuric acid is

9. The symbol of silver is

LONG QUESTIONS

Q. Define the following terms with examples;

**Symbol, Valency, Radical, Formula, Chemical
equation, Element, Compound, Equivalent weight.**

Q. What do you mean by chemical reaction? Explain its types with examples.

Q. Give the valency and formula of the following radicals:

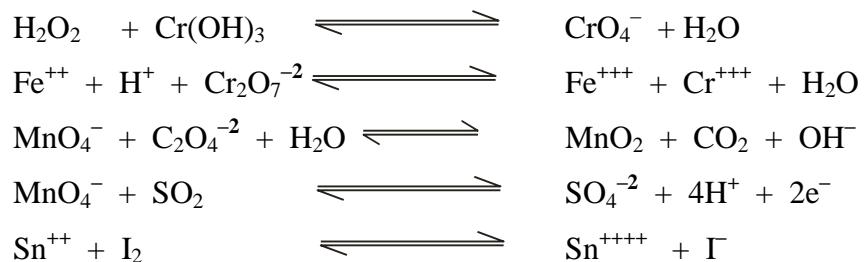
Ammonium, hydrogen, ferrous, stannic, chromium, Cupric,
bismuth, oxide, sulphate, phosphate, ferro-cyanide.

Q. Give the formula of the following compounds;

Carbonic acid, phosphoric acid, sodium sulphate, ammonium carbonate, ammonium phosphate, magnesium nitrate, ferrous sulphate, lead oxide, copper sulphate, aluminium sulphate, tin carbonate.

Q. What is the difference between a compound and mixture?

Q. Balance the given equations by the ionic or ion electron method;



Chapter 3

Atomic Structure

Course contents	2 Hrs
3.1 Sub atomic particles	
3.2 Bohr's atomic model	
3.3 Periodic classification of elements, periodic law	
3.4 General characteristics of a group and a period	

Learning outcomes:

After learning this chapter the student would be able to:

- 3.1 Define atom
- 3.2 Describe fundamental subatomic particles
- 3.3 Distinguish between atomic number, mass number and between isotope and isobars
- 3.4 Explain the arrangement of electrons in different shells and sub energy levels and understand Bohr's atomic model
- 3.5 Explain the grouping and placing of elements in the periodic table especially Silicon and germanium
- 3.6 State the periodic law of elements
- 3.7 Explain general characteristics of a group and a period

INTRODUCTION

Atom is the smallest particle of an element that may or may not exists alone but takes part in a chemical reaction. Or atom is the smallest particle of an element that can enter into a chemical reaction is called an *atom*. **John**

Dalton in 1808 gave the idea about the atoms in the matter. Atoms can only be seen through electron microscope.

Around 400 BC, *Democritus*, a Greek philosopher suggested that all matter is composed of tiny, indivisible particles, which he called atoms. The word Atom is derived from a Greek word ‘*atomos*’ which means ‘*indivisible*’.

Architecture of atom:

Different experiments have proved that atom is an unstable neutral particle and is the smallest object that has shape, size and mass. Atom is of round or spherical shape. Atom can be divided into two parts;

1. Extra-nuclear part
2. Nuclear part

1. Extra-nuclear part:

This part of the atom is located outside the nucleus of the atom and it surrounds the nucleus. This part contains only electrons, which continuously revolve around the nucleus in their fixed path called orbit, shell or energy level. The number of electrons is always equal to the number of protons present in the nucleus that is why atom is neutral in nature. The chemical properties of atom depend upon the number of electrons present in the outer most shell of an atom. *J.J.Thomson* discovered the electron in 1897.

Electron:

It is a negatively charged particle, which has a mass equal to 9.11×10^{-31} Kg in S.I unit. Its mass is $\frac{1}{1836}$ times as compared to a proton. The charge on electron is equal to that of proton that is -1.6022×10^{-19} Coulomb or 4.802×10^{-10} E.S.U. (Electro Static Unit). It is represented by “e⁻”

2. Nuclear part:

The central part of the atom is called nucleus. Probably all the mass of the atom is due to the nucleus. Until now more than 36 fundamental particles

of nucleus called “*nucleons*” has been discovered so far. It is said to be stationary and the physical properties of an atom are due to the nucleus. It also contains a tremendous amount of stored energy. Examples of the subatomic particles found in the nucleus are: hypron, neutrino, anti neutrino etc. The two fundamental sub atomic particles i.e. proton and neutron are discussed here:

i. Proton

It is a positively charged particle present in the nucleus, which has a mass equal to 1.6726×10^{-27} Kg or 1.6726×10^{-24} g in S.I unit. The charge on proton is equal to that of electron that is $+1.6022 \times 10^{-19}$ Coulomb. It is 1837 times heavier than electron. The number of protons is always equal to the number of electrons present in the nucleus of an atom. It is represented by “p”. *Goldstein* discovered the proton in 1886.

ii. Neutron:

Neutron has no charge and has a mass equal to 1.67492×10^{-27} Kg or 1.67492×10^{-24} g in S.I unit. It is 1842 times heavier than an electron. Neutrons are also present in the nucleus of an atom. *Chadwick* discovered neutron in 1932. It is represented by “n”.

ATOMIC NUMBER & ATOMIC MASS

Following are the differences between atomic number and atomic mass or mass number given in tabular form: -

S.#	Atomic number	Mass number
1.	The number of positive charges present on the nucleus or the number electrons present in atom of an element is called atomic number.	It is the total number of particles (protons & neutrons) present in the nucleus of an atom of an element.
2.	It represents the number of protons present in the nucleus of an atom.	It represents the total number of nucleons i.e., protons and neutrons present in the nucleus of an atom.
3.	It is represented by “Z”.	It is represented by “A”.

4.	It is unique for each element.	Two or more elements can have same mass number i.e., it is not a unique property.
5.	It has no unit.	Its unit is a.m.u i.e., atomic mass unit.
6.	It is also called proton number.	It is also called mass number.
7.	For example the atomic number of carbon is '6'.	For example the mass number of carbon is '12'.

Relation between atomic, mass and neutron number:

In general atomic mass or mass number of an atom is sum of its proton and neutron number and it is represented by "A". Atomic number of an atom represents number of protons present in the atom and it is denoted by "Z". The number of neutron in an atom is represented by "N". If any two of the quantities are known the third one can be found by the general relation

$$A - N = Z$$

Here A is atomic mass, Z is atomic number and N is neutron number.

ISOTOPES & ISOBARS

Following are the differences between isotopes and isobars:

S.#	Isotopes	Isobars
1.	The atoms of the same element having same atomic number but different mass number are called isotopes.	The atoms of different elements having almost same mass number but different atomic number are called isobars.
2.	It is the characteristic of one element.	It is the characteristic of more than one element.
3.	Most isotopes are unstable.	All isobars are stable.
4.	Isotopes show same chemical properties but different physical properties.	Isobars show different chemical as well as physical properties.
5.	For example there are two isotopes of chlorine i.e., $^{35}\text{Cl}^{35}$ & $^{37}\text{Cl}^{37}$. Hydrogen has three isotopes $^1\text{H}^1$, $^1\text{H}^2$ & $^1\text{H}^3$.	For example Calcium and Argon with mass number 40 each & $^6\text{C}^{14}$ and $^7\text{N}^{14}$ are isobars.

Shell and sub-shells (orbit & orbitals)

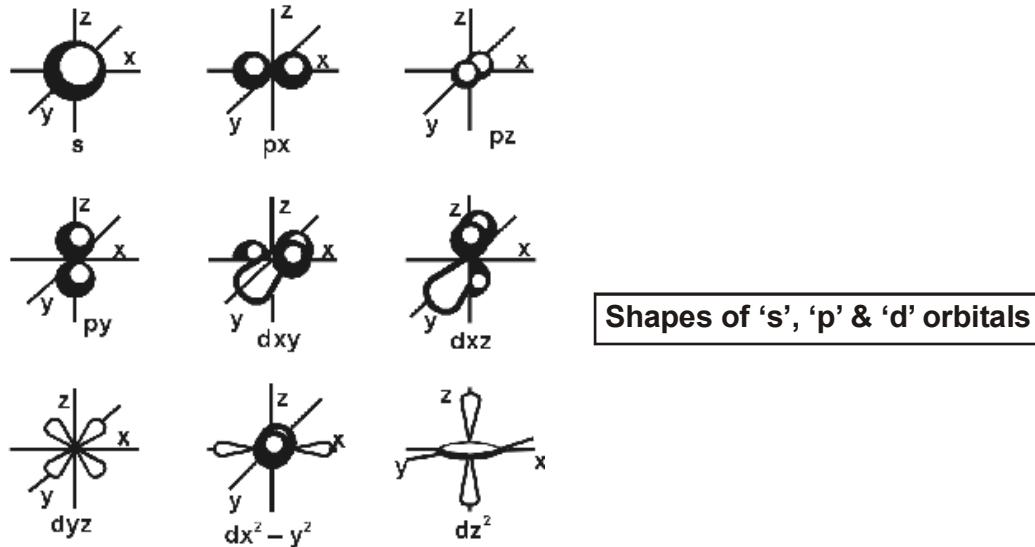
A shell is also called the ‘*orbit*’ or ‘*energy level*’. It is defined as the region around the nucleus where the probability of finding electron is maximum or it is the imaginary path around the nucleus where the electron revolves. There are different shells named as K, L, M, N, O, P, Q etc. these shells are further subdivided according to their numbers in to sub shells namely s, p, d, & f. The ‘s’ sub shell is spherical in shape, while ‘p’ sub shell is dumbbell in shape having three lobes along with three coordinate axis namely px, py, & pz. The ‘d’ sub shell has five lobes while ‘f’ sub shell has seven lobes. Each sub-shell or orbital can accommodate two electrons only and these are with opposite spins.

The shells are usually designated as K, L, M, N, O, P, Q etc as for orbits 1, 2, 3, 4, 5.... The nearest shell to the nucleus is ‘K’ and each orbit has its own specific radius. Electron moving in a particular shell is associated with definite amount of energy, so these shells or orbits have definite energy and are also called ‘*energy levels*’. Maximum number of electrons in these energy levels is determined by the formula “ $2n^2$ ” where ‘n’ is the number of shell. The maximum number of electrons that a shell or a sub shell can have is given below:

‘n’	Shell	Sub-shell	No. of electrons
1.	K	s	2
2.	L	s, p	2, 6
3.	M	s, p, d	2, 6, 10
4.	N	s, p, d, f	2, 6, 10, 14

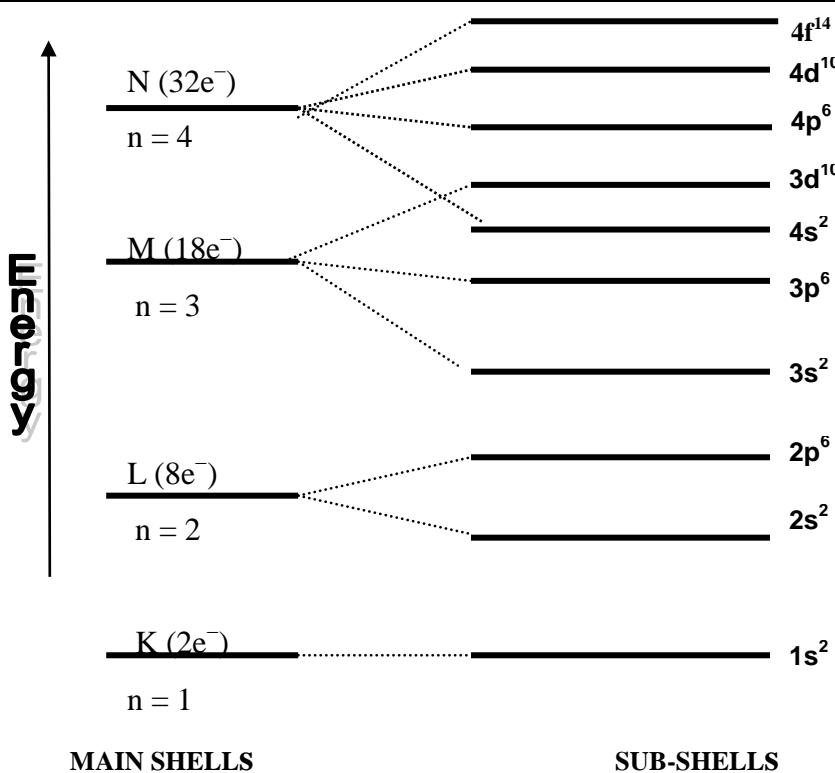
The outer most shell cannot accommodate more than 8 electrons and also the 2nd last shell cannot accommodate more than 18 electrons. The outer most shell is also called *valence orbit* and the electrons that it accommodates

are called *valence electrons*. The maximum number of electrons in the s, p, d and f sub-shells or orbitals or sub-energy levels is 2, 6, 10 and 14 respectively. The number of lobes in sub orbitals, s, p, d and f are 1, 3, 5, and 7 respectively. The diagram of s, p, and d sub-shells are given below:



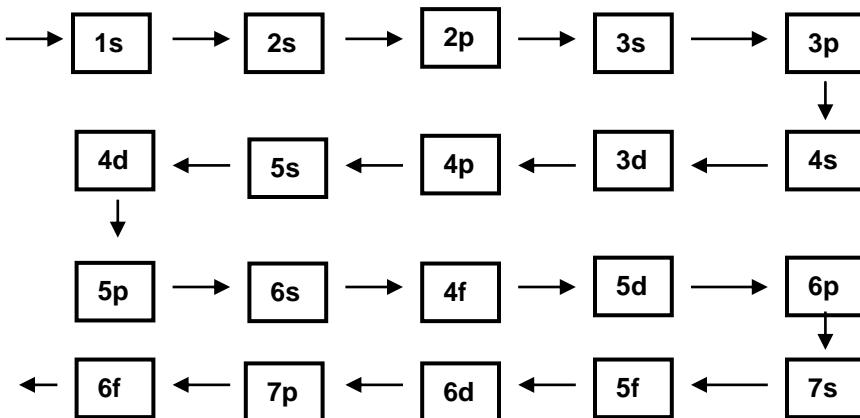
Energy levels of orbitals:

The quantum numbers tell us the shapes, orientations and energies of the atomic orbitals. Each energy level for a given sub-shell i.e., p, d and f have nearly the same energy. It may be noted that the energy of 4s orbital is less than 3d orbital. Similarly $5s < 4d$ and $6s < 4f < 5d$. The relative energies of the different energy levels are shown in the figure below:



Order of filling of sub-shells:

The filling of electrons in different orbits is according to their increasing energy. As a result the electrons will first occupy an orbital with a lower energy and then to a high energy. The order in which the electrons will enter into sub-shells is 1s, 2s, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, 7p, 8s. Schematically the filling of sub-shells can be represented as follows:



Bohr's Atomic Model:

In order to remove the defects in Rutherford's atomic model Neil Bohr in 1913, a Danish Physicist presented his atomic model. Its important postulates are;

1. Electrons revolve in fixed orbits around the nucleus.
2. As long as an electron revolves in a fixed orbit its energy remains unchanged.
3. The electron loses energy when it jumps down from a higher orbit to a lower orbit and gains energy when it jumps up from a lower to a higher orbit.
4. The electron loses a quantum of energy when it jumps down from an orbit of higher energy level to a lower energy level. The energy is absorbed or emitted in the form of radiation and it is a discontinuous process. The frequency of the energy emitted is directly proportional to the difference in energy between the two levels.

$$E_2 - E_1 \propto v$$

$$E_2 - E_1 = h v$$

$$\Delta E = h v$$

Where E_1 = energy of the electron in 1st orbit

E_2 = energy of the electron in 2nd orbit

$$\Delta E = E_2 - E_1$$

v = Frequency of the energy emitted.

h = Planck's constant. Its value is 6.6256×10^{-27} ergs sec

or 6.6256×10^{-34} Joule sec.

5. The angular momentum (mvr) of an electron in any orbit is

$$mvr = \frac{nh}{2\pi}$$

Where m = mass of electron

v = velocity of electron

r = radius of the orbit

n = It is the number of an orbit. It is also called quantum number. In other words electrons have to be in these orbits. Its value may vary from 1 to infinite, i.e., 1, 2, 3. ∞ , and the permitted values of the circular momentum will be $\frac{h}{2\pi}, \frac{2h}{2\pi}, \frac{3h}{2\pi}, \frac{4h}{2\pi}$

Defects in Bohr's atomic model:

Bohr's model of hydrogen atom satisfactorily explain the stability of the atoms, ionisation energy and the spectra of hydrogen and hydrogen like ions such as He^{+2} , Li^+ , Be^{+2} , however it fails to explain the following:

- (i) The energy states of more complicated atoms.
- (ii) The fine structure in the line spectrum of the hydrogen like atoms.
- (iii) When the spectrum of hydrogen atom is taken in the magnetic field, some new lines are created (Zeeman effect), which cannot be explained by Bohr's theory.

Grouping and placing of elements:

The vertical columns in the periodic table are called groups while the horizontal rows are called periods. The elements having similar properties like electronegativity, valency, and number of electrons in the outer most shell etc are grouped together and then placed in the periodic table in the increasing order of their atomic numbers. In a group similar atoms having same valency are kept together. There are 8 groups and 7 periods in the periodic table.

Grouping and placing of Silicon (Si) and Germanium (Ge):

The atomic number of Si and Ge is 14 & 32 and atomic mass is 28 & 72.64 respectively. Both Si and Ge are metalloids i.e., their properties are in between metals and non-metals and have four electrons each that is half filled

outer most shell. Their atomic radius is $1.12 \text{ & } 1.20^{\circ}\text{A}$, Ionisation energy is 786 & 762 KJ/mol and density is 2.33 & 5.32 g/cm³ respectively. So these are placed in the IV-A group (carbon group) of the p-block of the periodic table.

PERIODIC CLASSIFICATION OF ELEMENTS AND PERIODIC LAW:

Classification of elements:

The table of elements in which elements are arranged according to their properties in the horizontal rows called periods and vertical columns called groups, is called periodic table of the elements.

Until now 111 elements have been discovered. It is very difficult to study and remember the properties and behaviour of all these elements individually. So these elements are placed in different groups and periods on the basis of similarities and differences. The process of arranging similar elements in one group and separating them from dissimilar atoms is called “*periodic classification*”. The table thus formed by the classification of elements is called the “*periodic table*”.

Elements primarily according to their properties are divided into metals and non-metals. Metals like mercury and gallium are in liquid state while all others are in solid state. Conductivity, malleability, ductility and metallic lustre are the peculiar properties of metals. Non-metals are mostly in gaseous state while a few occur in solid state. Poor conductivity, non-malleability etc are their properties.

Dalton's atomic theory states that atoms of different elements possess different atomic weights. This postulate of Dalton's atomic theory gave the idea of classification of elements. This also gives the idea of relationship of atomic masses of elements with their properties.

Mendeleev's periodic law:

In 1869, Mendeleev, a Russian Chemist discovered a rule for the classification of elements. He found that if elements are arranged in the order of their increasing atomic weights, their properties vary in a regular manner, from one member to another in a series. In other words elements show periodicity in their properties. He concluded that the physical and chemical properties of the elements are the periodic function of their atomic weights.

Modern Periodic law:

In 1913 Moseley, a British Physicist found that the atomic number is the fundamental property of an atom. With this discovery it was found that the physical and chemical properties of elements are the periodic function of their atomic number. This is called the "*periodic law*" or "*modern periodic law*". Which states that "When elements are arranged in order of increasing atomic numbers, the elements possessing similar (physical and chemical) properties are repeated in a regular manner" Or

"Physical and chemical properties of the elements are periodic function of their atomic numbers"

Placing and grouping of elements in periodic table.

As already stated the elements are placed or arranged in the periodic table according to their physical and chemical properties. The properties of the elements depend on their atomic numbers and the arrangement of electrons in the orbits and sub orbits of the atoms of the elements. The sub orbits are named as s, p, d and f and the elements in which the filling of electrons in their particular sub shells is either in process or complete are placed in that block that is s block, p block, d block and f block.

- **s- block elements**

The elements of first two groups that is 1-A and ll-A are called s block elements, as the filling of electrons in these groups are found in their outer most shell's suborbital "s".

- **p- block elements**

The elements founds in groups lll-A to Vlll-A are called p block elements, as the filling of electrons in these groups are found in their outer most shell's suborbital "p"

- **d- block elements**

The elements founds in groups lll-B toVlll-B are called d block elements, as the filling of electrons in these groups are found in their outer most shell's suborbital "d"

- **f- block elements:**

The elements founds in lanthanide and actinide series are called f block elements, as the filling of electrons in these groups are found in their outer most shell's suborbital "f"

PERIODIC TABLE OF ELEMENTS

PERIODIC TABLE OF ELEMENTS																																			
I-A		II-A		Transition elements																															
1	H 1.00794	2	Be 9.01218																																
2	Li 6.941	3	Be 9.01218	4	Be	5	Cr 50.9415	6	Mn 51.9961	7	Fe 55.847	8	VIII-B 58.9332	9	I-B 63.546	10	Fe 56.9815	11	O 12.011	12	Ne 20.180														
3	Na 22.9888	4	Mg 24.3050	5	Sc 44.9559	6	Ti 47.88	7	Cr 50.9415	8	Mn 54.9380	9	V-B 58.9332	10	Co 58.9332	11	Co 58.9332	12	P 14.0063	13	Si 15.9994	14	F 18.9984												
4	K 39.0938	5	Ca 40.078	6	Sc 44.9559	7	V 47.88	8	Cr 50.9415	9	Mn 54.9380	10	VII-B 58.9332	11	Cu 65.39	12	Zn 65.39	13	Al 28.0855	14	Ge 30.9738	15	Cl 32.0866	16	Ar 35.4522										
5	Rb 85.4678	6	Sr 87.62	7	Y 88.9059	8	Zr 91.224	9	Nb 92.9064	10	Mo 95.94	11	Mo (98)	12	Ru 101.07	13	Ga 72.59	14	Ge 74.9216	15	As 78.96	16	Kr 79.904	17	Xe 83.80										
6	Cs 132.905	7	Ba 137.327	8	*La 138.906	9	Hf 178.49	10	Ta 180.948	11	Ta 183.85	12	W 186.207	13	Re 190.2	14	Ru 192.22	15	Ir 195.08	16	Os 196.967	17	Sb 200.59	18	Te 204.59	19	At 207.2	20	Rn 208.980	21	Rn (209)	22	Rn (210)	23	Rn (222)
7	Fr (223)	8	Ra 226.02	9	+Ac 227.02	10	Fr (261)	11	Db (262)	12	Sg (263)	13	Bh (264)	14	Hs (265)	15	Mt (268)	16	Dy 157.25	17	Tm 162.50	18	Er 164.930	19	Yb 167.26	20	Lu 168.934	21	Lu 173.04	22	Lu 174.967	23	Lu (259)	24	Lu (260)
* Lanthanide series		58 Ce 140.112	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 154.965	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967																				
** Actinide series		90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np (244)	94 Pu (244)	95 Am (244)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)																				

GENERAL CHARACTERISTICS OF A PERIOD AND GROUP:

Characteristics of a group:

The vertical columns of elements arranged in the periodic table are called '*groups*'. Following are the general characteristics of groups:

1. All the elements in a group show similar valence shell electronic configurations.
2. All the elements of the same group have the same valency.
3. All the elements in a group show similar properties.
4. The elements of the same group form compounds with the similar formula.
5. The first member of each group differs from other members of the same group.
6. The metallic character of elements increases whereas the non-metallic character decreases in a group.
7. All members of a group have equal number of electrons in the valence shell.
8. The value of electro negativity, density and ionisation potential decreases in a group from top to bottom.
9. The number of orbitals and atomic size increases in a group from top to bottom.

Characteristics of a period:

The horizontal rows of elements in the periodic table are called '*periods*'. There are seven periods in the periodic table. The general characteristics of a period are:

1. The atomic number increases regularly from left to right in a period.
2. The metallic character increases and then decreases from left to right in a period.

3. The elements present at both ends of the period have more affinity for each other and so form stable compounds like those of alkali metals and halogens.
4. The physical state of elements from solid, liquid to gas changes from left to right in a period.
5. A period has the same number of orbitals.
6. The value of electro negativity and ionisation potential increases from left to right in a period.
7. The atomic size and metallic character decreases from left to right in a period.

Electronic configuration:

The arrangement of electrons in various orbits or shells as well as in sub orbits or subshells of an atom is called electronic configuration. It take place under some rules. The electronic configuration of important 20 elements is given below in the tabular form:

	Z	K	L		M			N				O			P			Q		
			1s	2s	2p	3s	3p	3d	4s	4p	4d	4f	5s	5p	5d	5f	6s	6p	6d	7s
H	1	1																		
Li	3	2	1																	
B	5	2	2	1																
C	6	2	2	2																
N	7	2	2	3																
O	8	2	2	4																
F	9	2	2	5																
Na	11	2	2	6	1															
Mg	12	2	2	6	2	1														
Al	13	2	2	6	2	1														
S	16	2	2	6	2	4														
Cl	17	2	2	6	2	5														
K	19	2	2	6	2	6														
Ca	20	2	2	6	2	6														
Fe	26	2	2	6	2	6	6													
Cu	29	2	2	6	2	6	10													
Zn	30	2	2	6	2	6	10													
Ag	47	2	2	6	2	6	10	2												
Bi	83	2	2	6	2	6	10	2	6											
U	92	2	2	6	2	6	10	2	6	0										

OBJECTIVE PART QUESTIONS

Q. Give short answer to the following questions:

1. Define isobars with one example.
2. Define isotopes with one example.
3. What are fundamental sub atomic particles? Give names.
4. What is the difference between orbit and orbital?
5. What is meant by periodic classification of elements?
6. State modern periodic law?
7. What is the basis for the periodic classification of elements?

8. Define group and period?
 9. What is the trend of atomic size of elements in a group?
 10. What is periodicity of properties?
 11. Explain the formula $A - N = Z$
 12. What is the trend of valency of elements in a period?

Q. Encircle the correct answer of the following MCQ's

- 8.** The groups present in the periodic table are
(a) 6 (b) 7
(c) 8 (d) 9

9. The periods in the periodic table are
(a) 6 (b) 7
(c) 8 (d) 9

10. The vertical columns in periodic table are called
(a) Periods (b) groups
(c) lines (d) series

11. The horizontal rows in periodic table are
(a) Periods (b) groups
(c) lines (d) series

12. Modern periodic law is based on
(a) Atomic number (b) atomic mass
(c) Neutron number (d) nucleons

13. The valency of all the elements present in same group is
(a) Different (b) multiples
(c) variable (d) same

14. The blocks in the periodic table are.
(a) 1 (b) 2
(c) 3 (d) 4

15. Atomic size, in a group from top to bottom
(a) Increases (b) decreases
(c) remain same (d) uncertain

16. until now elements has been discovered.
(a) 109 (b) 110
(c) 111 (d) 112

17. The smallest particle of an element that takes part in chemical reaction is
(a) An atom (b) a molecule
(c) radical (d) a compound

LONG QUESTIONS

1. Describe fundamental subatomic particles
 2. Distinguish between atomic number, mass number and between isotope and isobars
 3. Explain the arrangement of electrons in different shells and sub energy levels
 4. Discuss Bohr's atomic model and its defects
 5. Explain the grouping and placing of elements in the periodic table especially Silicon and germanium
 6. State the periodic law of elements
 7. Explain the trend of properties of elements based on their position in the periodic table



Chapter 4

Chemical bond

Course contents	2 Hrs
4.1 Nature of Chemical bond	
4.2 Electrovalent bond with example	
4.3 Covalent bond, polar and Non-polar, sigma & pi bonds with examples	
4.4 Co-ordinate covalent bond with example	

Learning outcomes:

After learning this chapter the students would be able to:

- 4.1 Define chemical bond
- 4.2 State the nature of chemical bond
- 4.3 Differentiate between electrovalent and covalent bonding
- 4.4 Explain the formation of polar & nonpolar bond, sigma & pi-bond with examples.
- 4.5 Describe the nature of co-ordinate covalent bond with examples

INTRODUCTION – NATURE OF CHEMICAL BOND:

Chemical bond is an electrostatic force of attraction that holds atoms together in a molecule. Atoms contain protons and neutrons in its nucleus and electrons are revolving around the nucleus. In a neutral atom the number of electrons and protons are equal. The orbit in which electron revolve are designated by K, L, M, N, O etc. The maximum number of electron which an orbit can have is given by $2n^2$ formula, where ‘n’ is the number of the orbit, its

value is 1,2,3,4 and 5 for K, L, M, N and O respectively. In the outer most orbit of an atom there must be 8 electrons except K shell where this number is 2. Outer most orbit of an inert gas has 2 or 8 electrons and they are stable. Other elements try to gain this arrangement of electron in their most orbits to get them stabilized. This arrangement of 2 or 8 electrons in the outer most or valence shell of an atom is attained either by transfer of electron between bonding atoms or sharing electron among them.

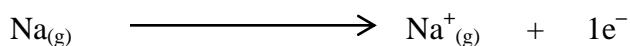
Depending upon the mode of attaining the inert gas configuration of 2 or 8 electrons in the outer most shells or orbits of atoms the bonds are divided into two main classes:

IONIC BOND OR ELECTROVALENT BOND:

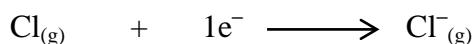
Such bond in which complete transfer of electron from one atom to another taken place such bond is called electrovalent or ionic bond. When an atom loses an electron it gets positive charge and when an atom gains electron it become negatively charged. The positive and negative charge atoms are called ions namely cations and anions respectively. Such opposite charge atom attract each other and a bond is formed between them. During this gaining or losing of electron atom gain the electronic configuration of 2 or 8 electrons in the outer most orbits and get them stabilized.

Example – 1:

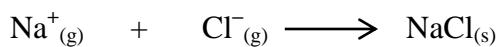
The formation of ionic bond between Na and Cl can be explained as Sodium has atomic number 11 where as of chlorine is 17. In order to attain the nearest noble gas electronic configuration Na loses one electron and Cl gains one electron.



Sodium by loosing one electron of its outer most orbit becomes positively charged and chlorine by gaining one electron becomes negatively charged.

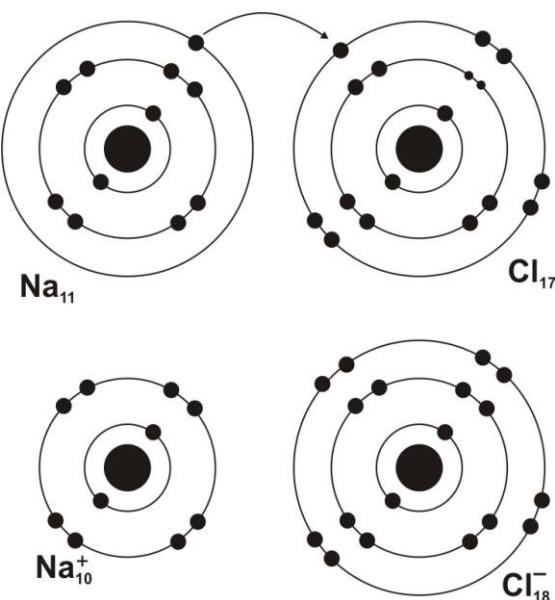


These two oppositely charged ions would attract each other by the electrostatic force of attraction to form ionic bond.



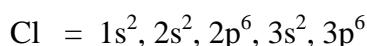
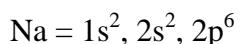
The electronic configuration of sodium and chlorine before and after the bond formation can be represented as;

Before bond formation				After bond formation		
Shell	K	L	M	K	L	M
Na-11	2	8	1	2	8	0
Cl-17	2	8	7	2	8	8



Formation of Ionic Bond

The new electronic arrangement can also be written as

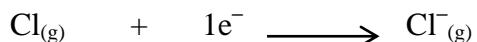


Example – 2:

Consider the formation CaCl_2 molecule. In this case each atom tends to attain a noble gas configuration. The atom, which loses an electron, becomes positively charged and is called a “*Cation*”. E.g.



And the atom, which gains an electron, becomes negatively charged and is called an “*anion*”. E.g.,

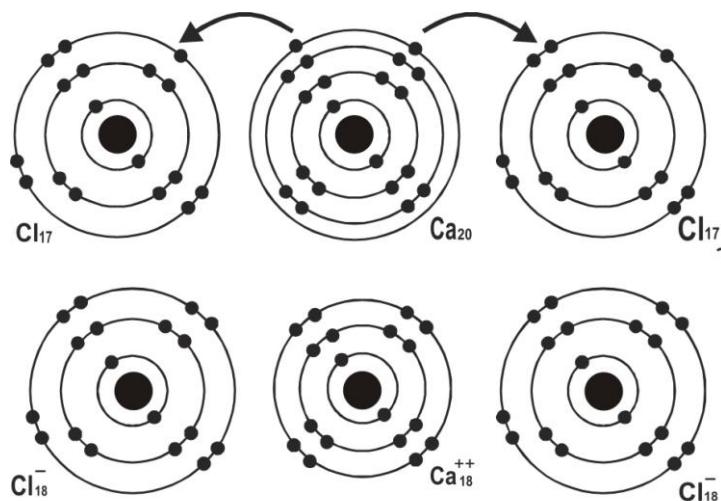


These two oppositely charged ions would attract each other by the electrostatic force of attraction to form ionic bond.

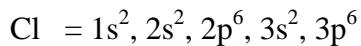
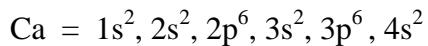


The electronic configuration of calcium and chlorine before and after the bond formation can be represented as;

Before bond formation					After bond formation			
Shell	K	L	M	N	K	L	M	N
Ca-20	2	8	8	2	2	8	8	0
Cl-17	2	8	7		2	8	8	



The new electronic arrangement can also be written as



COVALENT BOND:

G.N.Lewis in 1916 gave the idea of covalent bond. That type of chemical bond in which there is mutual sharing of electrons between the two similar or different atoms is called *covalent bond*. Or

The force of attraction that arises from the mutual sharing of electrons between two similar or different atoms is called *covalent bond*. More over the number of electrons shared by the reacting atoms are always equal. Atoms may form single, double or triple electron pair among themselves. It is to be noted that covalent bond is formed when formation of ionic bond becomes difficult or impossible.

Covalent bond is very common in organic compounds. In this bond electrons are shared in pairs. The number of covalent bonds formed by an atom is usually equal to the unpaired electrons in its valence shell. E.g., HCl, HBr, CH₄, CO₂, O₂, H₂, etc are the examples of covalent bond.

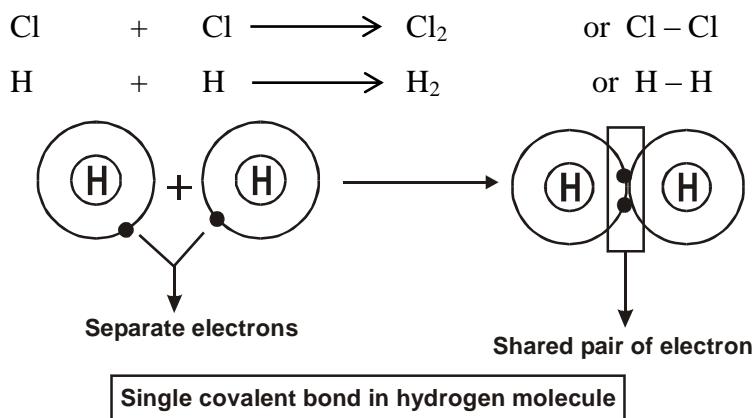
Types of covalent bond:

There are three types of covalent bond as the maximum number of covalent bonds that can be formed between two atoms is three, namely

1. Single covalent bond
2. Double covalent bond
3. Triple covalent bond

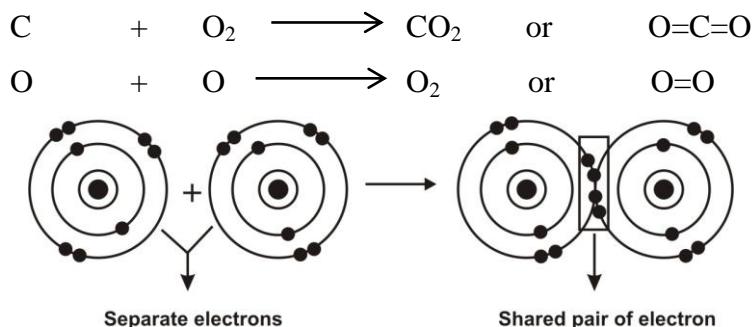
1. Single covalent bond:

That type of covalent bond in which there is mutual sharing of one electron each between the two bonded atoms is called single covalent bond. It is represented by a single line (—). E.g., H₂, Cl₂, HCl etc.



2. Double covalent bond:

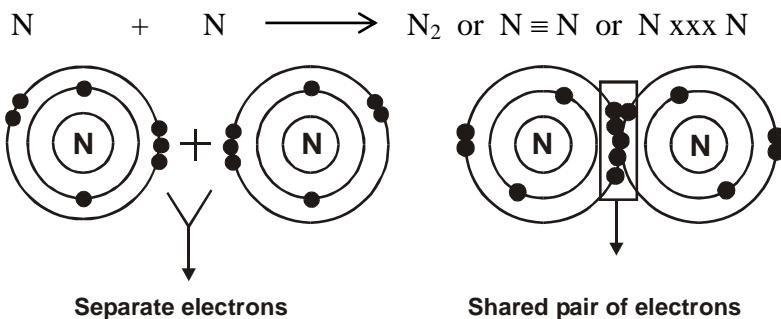
That type of covalent bond in which there is mutual sharing of two electrons each between the two bonded atoms is called double covalent bond. It is represented by a double line (=). E.g., O₂, CO₂, Ethene etc.



3. Triple covalent bond:

That type of covalent bond in which there is mutual sharing of three electrons each between the two bonded atoms is called triple covalent bond. It

is represented by a triple line (\equiv). E.g., N_2 , ethyne [$CH\equiv CH$], HCN [$H-C\equiv N$] etc.



Triple bond in nitrogen molecule

POLAR AND NONPOLAR COVALENT BOND:

Depending upon the polarity i.e., the degree of separation of charges in an atom or molecule, there are two types of covalent bond;

1. Polar covalent bond
2. Non-polar covalent bond

1. Polar covalent bond:

That type of covalent bond in which the shared electron pair is attracted unequally by the two atoms is called '*polar covalent bond*' or that type of covalent bond in which there is differentiation of positive and negative charge at the two end of the molecules called poles. The two different atoms usually form it and these show some electronegativity difference. These are somewhat like ionic compounds and have dipole moment. The bonded atoms have slight positive and negative charge. For example HCl , HBr , water etc.

2. Non-polar covalent bond:

That type of covalent bond in which the shared electron pair is attracted equally by the two atoms is called non-polar covalent bond or that type of covalent bond in which there is no differentiation of positive and negative charge between bonding atoms. It is usually formed by the two

similar atoms and has zero electronegativity difference. These have zero dipole movement. The bonded atoms have no charge at all because there is an equal distribution of charge. Such bond is called ‘pure covalent bond.’ For example all diatomic gases like H₂, O₂, Br₂, Cl₂, N₂, etc.

MODERN INTERPRETATION OF COVALENT BOND:

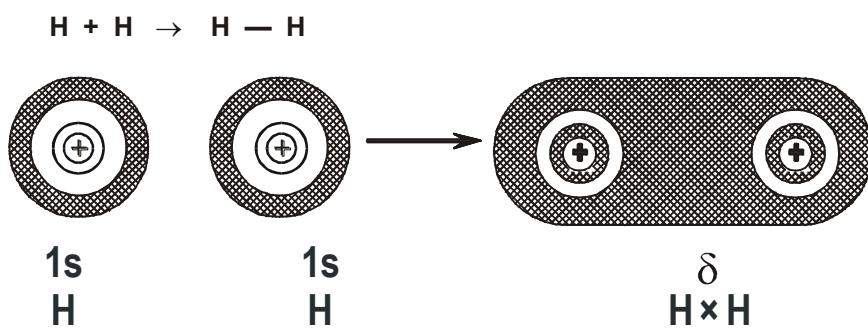
The basic idea behind the modern concept of the covalent bond is that “the sub orbits of atoms are supposed to have certain contours or shapes and instead of only sharing electrons the partially filled orbital of the bonding atoms lie in the same space i.e., the orbitals overlap. The overlapping of the orbitals of bonding atoms may be direct or head on, the overlapping may be indirect or parallel.

Depending upon the mode of bond formation and overlapping of the bonding atom’s orbitals, the modern two types of covalent bond are as under

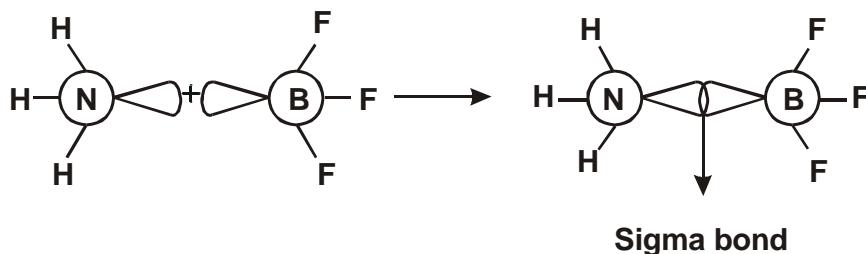
1. Sigma bond
2. Pi bond

1. Sigma bond (σ -bond):

If the axes of overlapping orbitals are in one line that type of covalent bond is called sigma bond. Or a bond formed between two atoms by the end-to-end or head on overlap of the half-filled atomic orbitals is called ‘ σ -bond’. The bonding orbitals are always in the straight line and have common axis. It is quite a stronger bond. Only one σ -bond can be formed between the two atoms. All the single covalent bonds are σ -bonds. For example overlap of the s-s orbitals, px-px orbitals, & s-p orbitals.



Formation of sigma bond in hydrogen

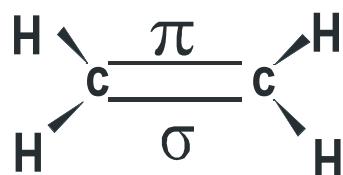
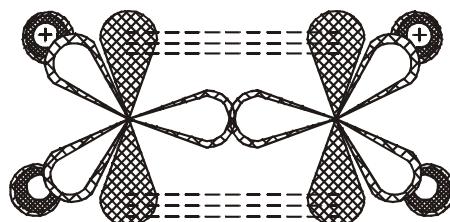
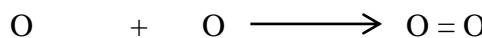


Sigma bond between NH_3 & BF_3

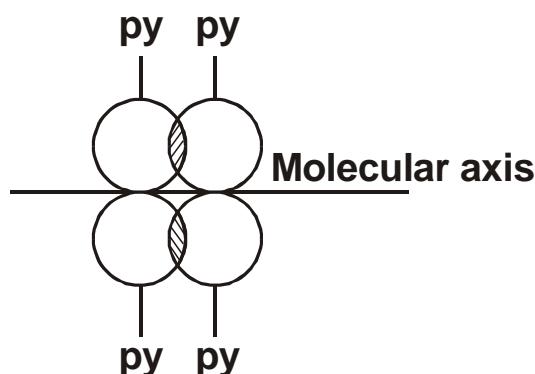
2. Pi bond (π -bond):

If the axes of overlapping orbitals are parallel to one another that type of covalent bond is called pi bond. Or a bond formed between two already bonded σ -bond atoms by the parallel or side-wise overlap of the half-filled atomic orbitals is called ' π -bond'. The bonding orbitals must be co-planer and should have parallel axis. It has two regions of electron density that are above and below the bond axis. It is quite a weaker bond. It is always formed after the sigma bond. Moreover it cannot exist alone. One or two π -

bond can be formed between the two atoms. For example py-py orbitals, p_z-p_z orbitals & one pi bond oxygen molecule and two pi bonds in nitrogen molecule etc.



Pi-bond in ethene molecule

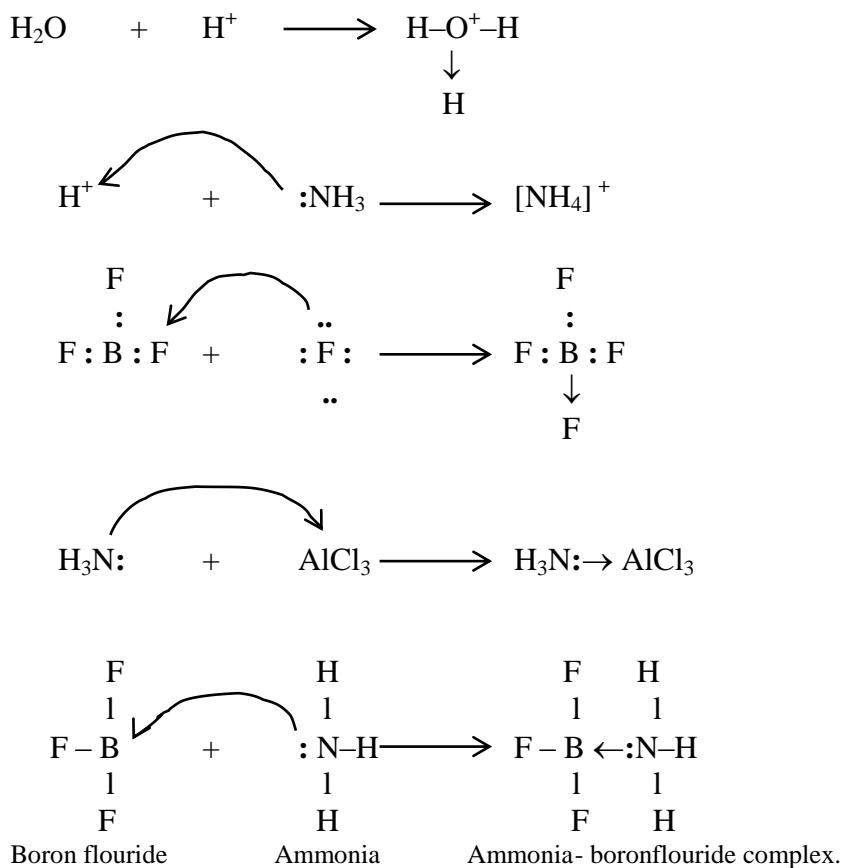


Parallel overlapping of 'py' orbitals

CO-ORDINATE COVALENT BOND:

A bond formed by the sharing of an electron pair that is donated by any one of the bonded atoms is called *co-ordinate covalent bond*. Or

A bond formed by the shared pair of electrons contributed by one atom only is called *co-ordinate covalent bond*. The specie (atom, ion or molecule), which donates an electron pair, is called ‘*Donor*’ atom, while the specie that accepts an electron pair is called ‘*Acceptor*’ atom. So simply it is ‘*donor-acceptor covalent bond*’. Only one co-ordinate covalent bond can be formed between the two atoms. A co-ordinate covalent bond is generally represented by an arrow (\rightarrow) pointing from the donor atom to the acceptor atom. For example H_3O^+ , NH_4^+ have *co-ordinate covalent bond* etc.



Differences between ionic and covalent bond

Following are the major differences between ionic and covalent bonds, given in the tabular form:

S.#	Ionic bond	Covalent bond
1.	The electrostatic force of attraction between the oppositely charged ions is called an electrovalent bond.	The force of attraction that arises by the mutual sharing of electrons between two atoms is called a covalent bond.
2.	It is formed by the complete transfer of one or more electrons from a metal atom to non-metal atom.	It is formed by the mutual sharing of electrons between the two bonded atoms.
3.	It involves one, two or three electrons transfer between the two bonded atoms.	It involves one, two or three pairs of electrons between the two bonded atoms.
4.	The migrated electrons belong to only one of the two bonded atoms.	The shared electrons belong to both of the bonded atoms.
5.	It is represented by placing complete positive and negative charges on the bonded atoms.	It is represented by a small line (-) drawn between the two bonded atoms.
6.	It is a non-directional bond.	It is a directional bond.
7.	It has not any types .	It has different types.
9.	If the difference of electronegativity between the combining atoms is more than 1.7 ionic bond will be formed.	If the difference of electronegativity between the combining atoms is less than 1.7 covalent bond will be formed.
10.	Ionic bond is always formed between atoms of different elements.	Covalent bond is formed between atoms of same or different elements.

OBJECTIVE QUESTIONS

Q. Give short answers to the following questions:

1. Define chemical bond.
2. Define ionic bond what is its second name.

3. Define covalent bond name its types.
 4. Differentiate between single, double and triple covalent band
 5. Write two differences between ionic and covalent band.
 6. What is basic difference between covalent and coordinate covalent band?
 7. State octet rule.
 8. What is co-ordinate covalent bond?
 9. Define pi bond and sigma bond.
 10. Indicate the type of covalent bond in H₂, O₂, N₂, and CH₄.
 11. Describe the formation of polar covalent bond.
 12. Describe the formation of non-polar covalent bond.

Q. Encircle the correct answer from the following MCQ's.

LONG QUESTIONS

1. Define chemical bond, explain ionic bond?
 2. What is covalent bond explain single, double and triple covalent bond?
 3. Discuss coordinate covalent bond with examples?

4. Clearly differentiate between ionic and covalent bond?
5. What do you mean by polar and nonpolar covalent bond explain with examples?
6. How sigma and pi bonds are formed clarify with examples?



Chapter 5

Solids & Liquids

Course contents**3 Hrs.**

- 5.1 The Liquid and Solids state.
- 5.2 The liquids and their general properties (Density, Viscosity Surface Tension, Capillary Action etc.)
- 5.3 Solid and their general Properties.
- 5.4 Crystal structure of Solids.
- 5.5 Crystal of Si and Ge.

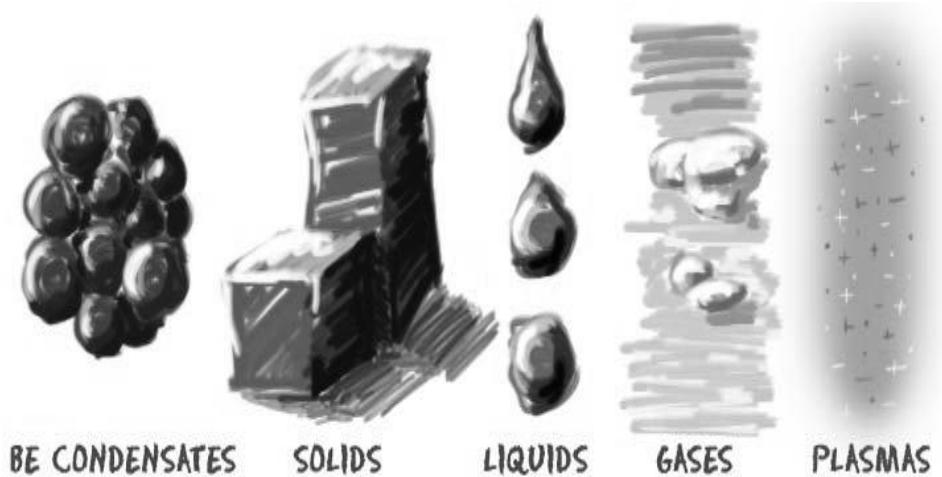
Learning outcomes

After learning this chapter the student would be able to:

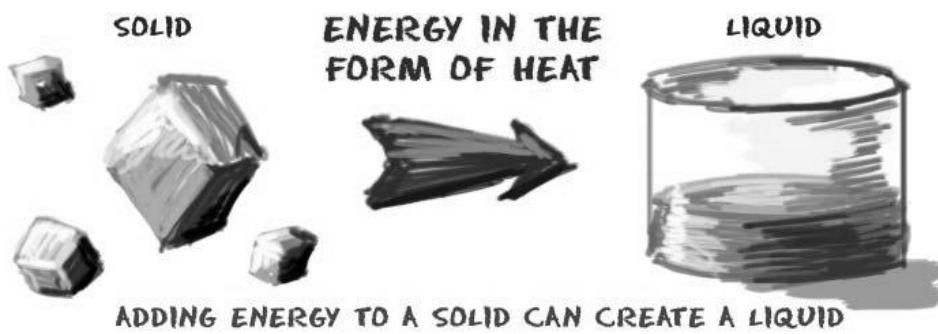
- 5.1 Describe the Liquid and Solid state of matter.
- 5.2 State the general properties of Liquid.
- 5.3 State the general properties of Solid.
- 5.4 Explain the formation of crystals and their types.
- 5.5 Describe the crystal structure of Si and Ge.

INTRODUCTION

Matter is everything around us. Atoms and molecules are all composed of matter. Matter is anything that has mass and occupies space. Mass is the amount of stuff in an object. Matter can be found all over the Universe. It is present in a few forms on Earth. There are five phases of matter – solids, liquids, gases, plasma and Bose-Einstein.



Plasma is an ionized gas. It is a cloud of protons, neutrons and electrons
On earth, plasma is naturally occurring in flames and lightning.

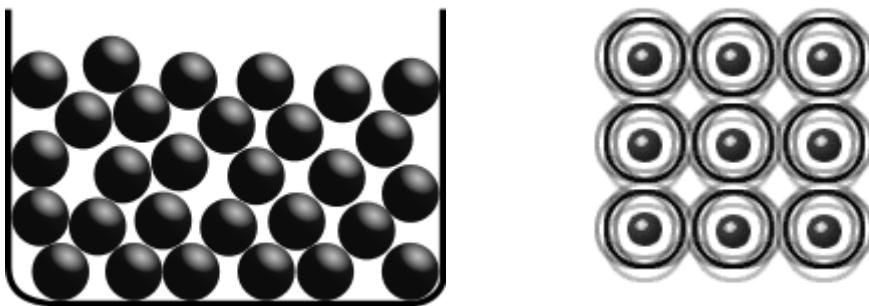


Bose-Einstein condensate

The collapse of the atoms into a single quantum state is known as Bose-Einstein condensate. Bose-Einstein condensate is the opposite of plasma. It occurs at ultra-low temperature.

Liquid

A liquid is a nearly incompressible fluid that takes the shape of its container but retains a (nearly) constant volume independent of pressure. When a solid is heated above its melting point, it becomes liquid. E.g oil, water etc



Solid

A solid has a stable, definite shape, and a definite volume. Eg book, chair etc

General Properties of Liquids

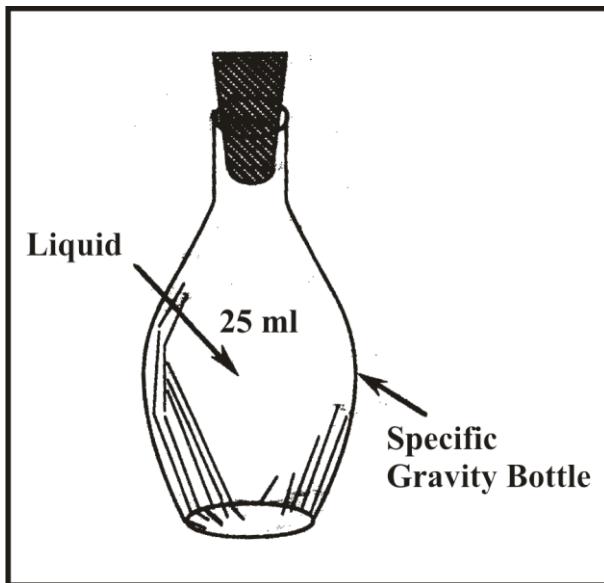
All liquids show the following properties:

- (i) Liquids are almost incompressible but less incompressible than solids.
- (ii) Liquids have fixed volume but no fixed shape.
- (iii) Liquids flow from higher to lower level.
- (iv) Liquids have their melting points below room temperature and boiling points above room temperature, under normal conditions.
- (v) Density

Mass per unit volume is called density. Density of a solid can be measured by taking its length, width and breadth (volume of a solid) and mass. But density of a liquid can be measured by specific gravity bottle.

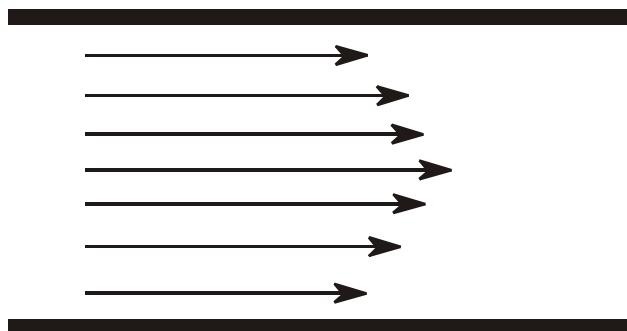
The formula for determining the density is given below.

$$d = \frac{m}{v}$$

**MEASUREMENT OF DENSITY****(vi) Viscosity**

“The internal resistance to flow of a liquid is called the Viscosity of liquid”. It is represented by “ η ”

In order to understand viscosity; consider the flow of a liquid in a tube.

**Representation of viscosity**

Assume that the liquid consists of a number of molecular layers arranged one over the other. It is observed that the layer of the liquid that is in contact with the walls of the tube is almost stationary. But as the distance from the wall of the tube increases, the velocity of the flowing liquid also increases and becomes maximum at the centre of the tube. Now, a layer, which is moving slowly, will try to decrease the velocity of the adjacent fast moving layer. Thus, each layer of a liquid exerts a drag on the next layer due to internal friction. This internal resistance is called the viscosity of the liquid.

Units of viscosity:

The SI unit of viscosity is called $\text{Kg.m}^{-1}\text{s}^{-1}$. The CGS unit of viscosity is Poise (p). It is usually measured in centi-poise (cp).

$$1 \text{ p} = 100 \text{ cp}$$

$$1 \text{ p} = 1/10 \text{ Kg.m}^{-1}\text{s}^{-1}$$

For example the viscosity of water at 25°C is 1 centi-poise.

The relative viscosity is measured by the following formula;

$$\eta_r = \frac{d_l t_l}{d_w t_w} \times \eta_w$$

Where

η_l = Coefficient of viscosity for liquid

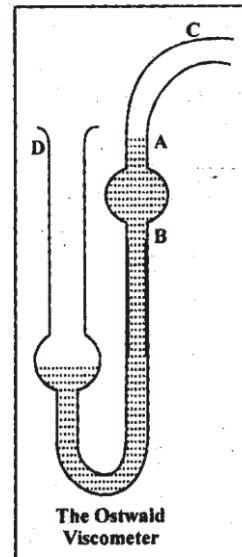
η_w = Coefficient of viscosity for water

t_l = Time taken for liquid to move from 'A' mark to 'B'

t_w = Time taken for water to move from mark 'A' to 'B'

d_l = Density of liquid

d_w = Density of water



(vii) Surface Tension

The amount of energy required to expand the surface of a liquid by a unit area is called the *surface tension* of the liquid. Or the unbalanced downward attractive force present on the surface of a liquid is called *surface tension*. Or

The vertical force acting on the unit length on the surface of a liquid is called *surface tension*. It is denoted by “ γ ” (gamma).

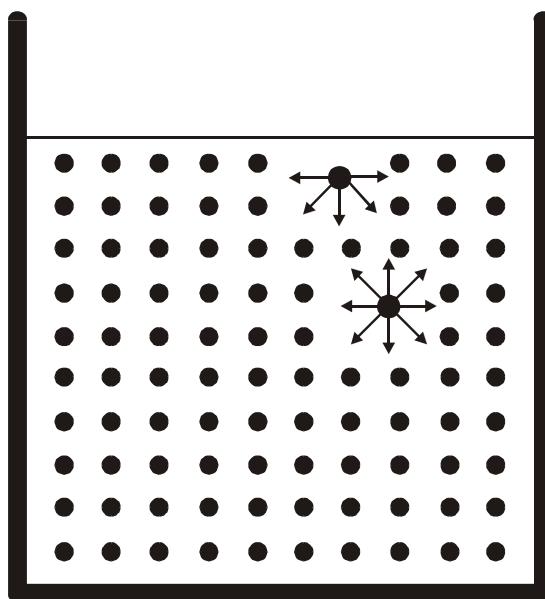
Units of surface tension:

The unit of surface tension is Newton per metre, Nm^{-1} , Joule per square metre, Jm^{-2} , dynes/cm or erg/cm².

Explanation:

The surface tension of a liquid is due to the cohesive forces present between the molecules. These forces on the surface molecules are different from those on the molecules, which are below the surface.

A molecule, which is below the surface of the liquid, is attracted equally from all directions by the surrounding molecules. The net resultant force acting on it is zero. However the molecule present on the surface of the liquid is attracted by the molecules on its sides and below it. There is no attractive force present on the upper side of the surface molecules. Thus the surface molecules are attracted downward. This inward attraction creates the surface tension. For a molecule to come out of the surface, it must overcome to this inward attraction. So this downward pull is called surface tension. The surface of liquid thus appears like a stretched membrane. It is so strong that it can hold the weight of small floating insects.



Surface tension

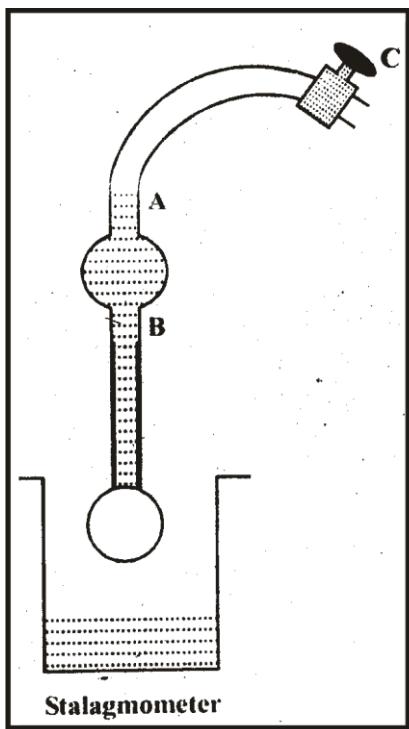
Measurement of surface tension:

The surface tension of a liquid can be measured by the following methods;

Liquid is filled in the dry clean Stalagmometer upto 'x' and then it is allowed to flow down slowly in the form of drops from point 'A' to 'B'. The number of drops formed with water and the number of drops formed with the same volume of another liquid are counted at the constant pressure. Surface tension is then calculated by the following formula;

$$\gamma_{\ell} = \frac{n_w d_{\ell}}{n_{\ell} d_w} \times \gamma_w$$

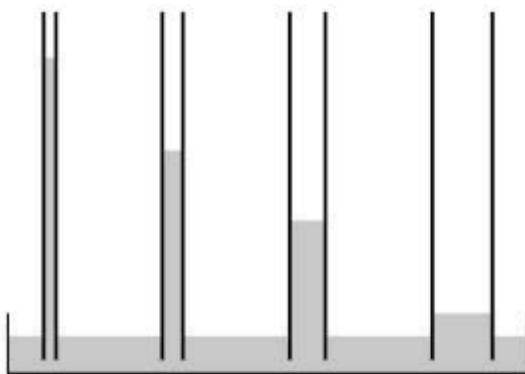
Where γ_{ℓ} , d_{ℓ} and n_{ℓ} are the surface tension, density and number of drops of the given liquid and γ_w , d_w and n_w are corresponding values for water.



(viii) Capillary action

The spontaneous rise of a liquid in a capillary tube against the force of gravity is called *capillary action*.

When a capillary tube is placed vertically in water, it rises up in the capillary tube. Water will continue to rise until upward force due to surface tension is balanced by the downward gravitational force due to the weight of the liquid. This rising up of the liquid in a capillary occurs because the adhesive force between water molecules and the glass surface is stronger than the cohesive force between the water molecules. If we take a number of capillary tubes having different diameters, the narrowest capillary will show the highest rise of water.



Capillary Action

General Properties of Solids

All solids show the following properties:

- (i) Solids are rigid, and incompressible.
- (ii) Solids have fixed shape and definite volume.
- (iii) Solids have their melting and boiling points above room temperature.
- (iv) Solids have their specific colours.
- (v) Solids have their specific mass.
- (vi) Solids have their own density values.
- (vii) Solids have definite volume.
- (viii) Solids have their own hardness.
- (ix) Conductivity (both thermal and electrical) of different solids is different.

Types of Solids

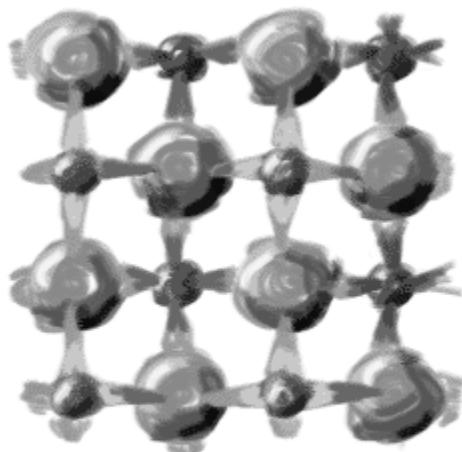
Generally there are three types of solids;

1. Crystalline solids:

The solids in which the structural units – atoms, ions or molecules are arranged in a regular repeating three-dimensional manner are called crystalline solids. These have sharp melting points. For example NaCl, KCl etc.

2. Amorphous solids:

The word ‘*amorphous*’ means ‘*shapeless*’. The solids without any definite shape are called amorphous solids. Or the solids in which the atoms, ions or molecules are arranged in a random or non-repetitive three-dimensional manner are called amorphous solids. These are actually powdered



A CRYSTAL LATTICE IS A REPEATING GEOMETRIC ARRANGEMENT OF ATOMS

solids. When crystalline solids are crushed, their particles lose their regular geometrical shapes and become amorphous. These do not have sharp melting points.

For example plastic, rubber and polystyrene.

3. Vitreous solids:

The super cooled liquids are called vitreous solids. For example glass is a vitreous solid.

TYPES OF CRYSTALS

There are four types of crystals depending upon the nature of bond present between them;

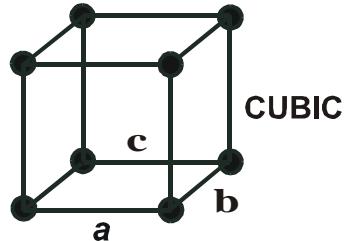
1. **Metallic crystals:** For example metals like Cu, Fe etc.
2. **Ionic crystals:** For example NaCl, KCl etc.
3. **Covalent crystals:** For example Si and Ge crystals etc.
4. **Molecular crystals:** For example H₂O, I₂, NH₃ etc.

Crystal systems:

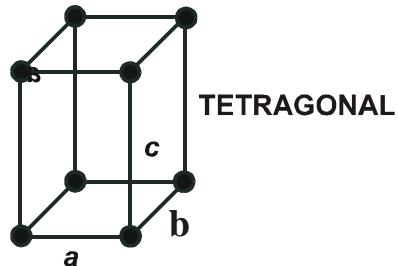
There are seven lattice systems. They are similar to but not quite the same. Lattices can either be primitive (only one lattice point per unit cell) or non-primitive (more than one lattice point per unit cell). Each lattice system consists of a set of three axes in a particular geometric arrangement.

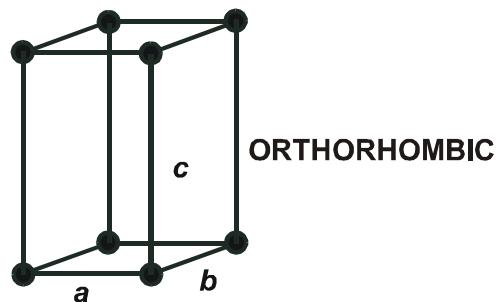
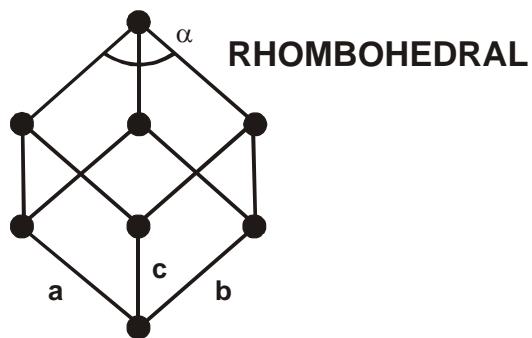
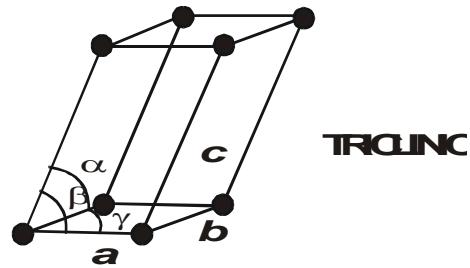
Different crystals are classified into 7 fundamental types known as '*crystal system*'. These all vary with respect to the length of the edges and angles. These are;

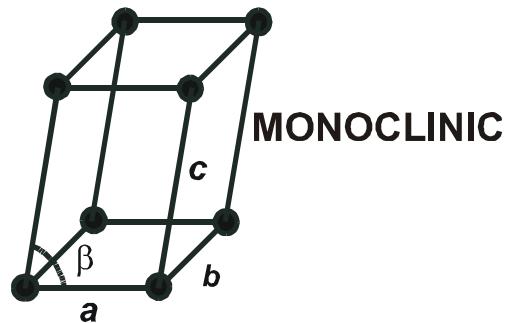
1. Cubic system:



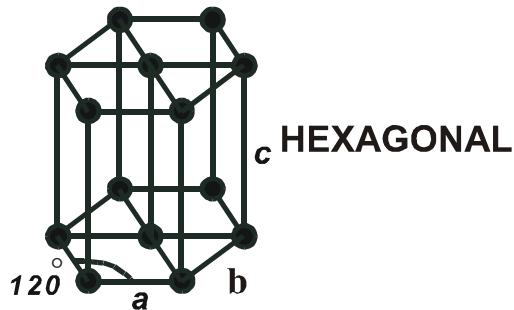
2. Tetragonal system:



3. Orthorhombic or rhombic system:**4. Rhombohedral or trigonal system:****5. Triclinic system:****6. Monoclinic system:**



7. Hexagonal system:



S. #	Crystal system	Axis	Angles	Examples
1.	Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90^\circ$	Fe, Cu, NaCl, NaBr, Diamond
2.	Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	Sn, SnO ₂ , MnO ₂ , NH ₄ Br
3.	Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	I ₂ , KNO ₃ , rhombic sulphur
4.	Monoclinic	$a \neq b \neq c$	$\alpha = \gamma = 90^\circ$ and $\beta > 90^\circ$	Sugar, sulphur, borax
5.	Hexagonal	$a = b \neq c$	$\alpha = \beta = 90^\circ$ $\gamma = 120^\circ$	ZnO, CdS, graphite
6.	Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90^\circ$ $< 120^\circ$	Bi, Al ₂ O ₃ , NaNO ₃ , KNO ₃
7.	Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	H ₃ BO ₃ , K ₂ Cr ₂ O ₇ , CuSO ₄ .5H ₂ O

Crystal Formation

Crystal is a solid which possesses a definite geometric shape, and the process by which these crystals are prepared is called crystallization. Crystals represent the substance in its purest form. The process of crystallization is based on difference in the solubility of the substance and impurity in a given solvent. For the preparation of pure crystals, saturated solution of impure substance after filtration is cooled slowly. At this temperature the motion of molecules becomes very slow and inter-molecular forces are very much effective and the molecules fit themselves in a definite geometric shape. These pure crystals are separated from the mother liquor by filtration.

Crystals can be formed by the following ways.

1- Evaporation

Crystals formed by evaporation form due to the fact that there is decreasingly less solvent available for the ions to be dissolved in, therefore causing a state of meta-stable or super-saturation in which nucleation (The moment a crystal begins to grow is known as nucleation) and crystal growth can occur.

2- Adjusting the pH

This method is commonly used to obtain homogenous nucleation and growth because we can control pH by various reactions. In doing this, we can effectively

make the change as slow as we want and make it completely uniform throughout the solution. The crystals again form because the extent to which the ions are soluble decreases when the pH is changed in the right direction.

3- Lowering the temperature

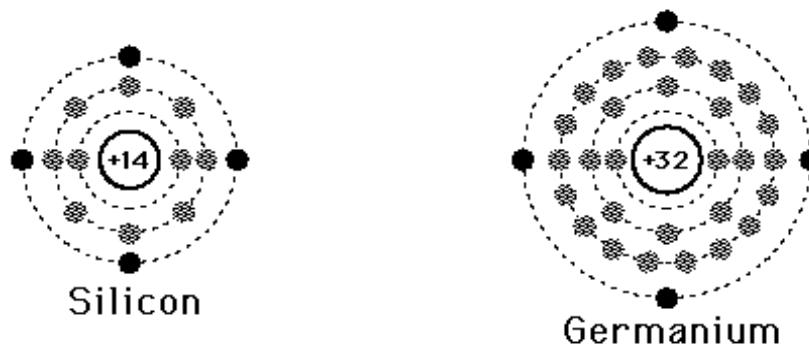
By lowering the temperature of the solvent, we can reduce the solubility of the ions and crystals formed.

4- Changing the nature of the solvent

This method is commonly used when a faster crystallization is desired. In order to change the nature of the solvent, one would normally add non-solvent (something which the ions are not soluble in, or not as soluble in) to the current solution. By doing this, we can effectively reduce the solubility of the ions in the solution and cause rapid precipitation.

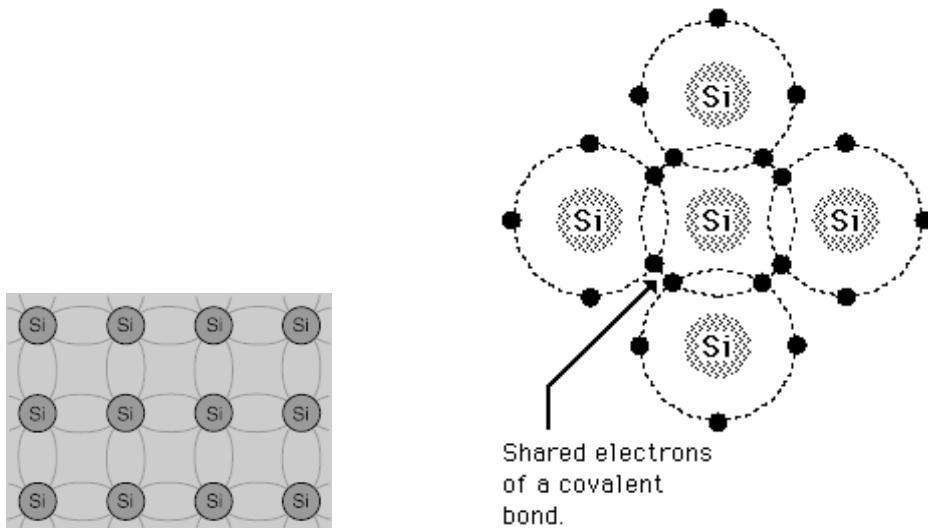
Crystal structure of Silicon and Germanium

Both Silicon (Si) and Germanium (Ge) belongs to IV A group that is carbon family. Their atomic numbers are 14 and 32, and atomic weights are 28.086 and 72.59, respectively. Their electronic configuration is 2, 8, 4 and 2, 8, 18, 4 respectively. These have half filled i.e., 4 electrons present in the outer most shells. These are metalloids i.e., their properties are in between metals and non-metals. The elements of 4th group are semi-conductors except carbon i.e. their properties are in between conductors and insulators.



Silicon Lattice

Silicon atoms form covalent bonds and can crystallize into a regular lattice. This crystal is called an intrinsic semiconductor and can conduct a small amount of current. A silicon atom is influenced by more than four other silicon atoms, as may be appreciated by looking at the silicon unit cell.



OBJECTIVE QUESTIONS

Q. Give short answers to the following questions:

1. Define solid and give its two examples.
 2. Define Liquid and give its two examples.
 3. Define crystal.
 4. Define Viscosity and give its unit.
 5. Define Surface Tension and give its unit.
 6. Describe Capillary Action.
 7. Give any two general properties of Solids.
 8. Give any two general properties of Liquids.
 9. Give any two examples of Amorphous Solids.
 10. Draw Atomic structure of Silicon.
 11. Draw Atomic structure of Germanium.
 12. Give two examples of cubical system.

Q. Encircle the correct answer from the following MCQ's.

1. In ----- solids, the particles (atoms, molecules, or ions) are packed in a regularly ordered, repeating pattern.

2. Viscometer is made up of

3. Surface Tension is measured in

4. Unit of Viscosity is

- (a) gm/cm (b) dynes/cm
(c) Newton (d) poise

5. State of matter which has definite shape and definite volume is called

(a) solid (b) liquid
(c) gas (d) plasma

6. NaCl form crystals.

(a) cubic (b) monoclinic
(c) ortho-rhombic (d) tetragonal

7. KNO₃ form crystals

(a) cubic (b) monoclinic
(c) ortho-rhombic (d) tetragonal

8. Garaphite form crystals.

(a) cubic (b) monoclinic
(c) hexagonal (d) tetragonal

9. The atomic number of Silicon is

(a) 14 (b) 28
(c) 32 (d) 40

10. The atomic number of Germanium is

(a) 14 (b) 28
(c) 32 (d) 40

11. Silicon and Germanium, each of which has valence electrons.

(a) 4 (b) 5
(c) 6 (d) 7

12 NH₄Br, MnO₂, SnO₂, Sn etc are the examples of

(a) unit cell (b) cubic system
(c) tetragonal system (d) orthorhombic system

13. Silicon atoms form bonds and can crystallize into a regular lattice.

14. The fifth state of matter is

- (a) plasma
 - (b) solid
 - (c) Bose-Einstein condensate
 - (d) liquid

15. represent the substance in its purest form.

16. There are lattice systems.

17. Mass per unit volume is called

18. Specific gravity bottle is used for the measurement of

19. NaNO_3 , KNO_3 , Al_2O_3 , Bi etc are the examples of

20. The resistance of a liquid to flow is

- | | |
|----------------------|---------------------|
| (a) viscosity | (b) Surface Tension |
| (c) Capillary action | (d) density |

LONG QUESTIONS

1. Describe the Liquid and Solid state of matter.
2. State the general properties of Liquid.
3. State the general properties of Solid.
4. Explain the formation of crystals.
5. Explain the types of crystals.
6. Describe the crystal structure of Si and Ge.



Chapter 6

Water

Course contents 2 Hrs

- 6.1 Chemical nature and properties
- 6.2 Impurities
- 6.3 Hardness of water (type causes & removal)
- 6.4 Scales of measuring hardness
- 6.5 Boiler feed water, scales and treatment
- 6.6 Sea-water desalination, sewage treatment

Learning outcomes:

After learning this chapter the students would be able to:

- 6.1 Describe the chemical nature of water with its formula
- 6.2 Describe the general impurities present in water
- 6.3 Explain the causes and methods to remove hardness of water
- 6.4 Express hardness of water in different units
- 6.5 Describe the formation and nature of scale in boiler feed water
- 6.6 Explain the methods for the treatment of scale
- 6.7 Explain the sewage water treatment and desalination of sea water

INTRODUCTION

Water is the symbol of life and is present only on our planet – earth. It is hardly found in pure form as it is a universal solvent. It may contain dissolved, suspended, and biological impurities. Dissolved impurities are

responsible for water hardness while biological impurities are responsible for water borne diseases. Dissolved impurities like salts of Calcium and Magnesium can cause hardness of water. It can be removed by different common and separate methods. Different scales are also used to describe water hardness. Usually hardness of water is eliminated in boiler feed water. Sewage treatment is carried out in modern world to avoid water pollution. Then lastly different procedures are discussed to make sea water into portable drinking water.

Chemical nature of water:

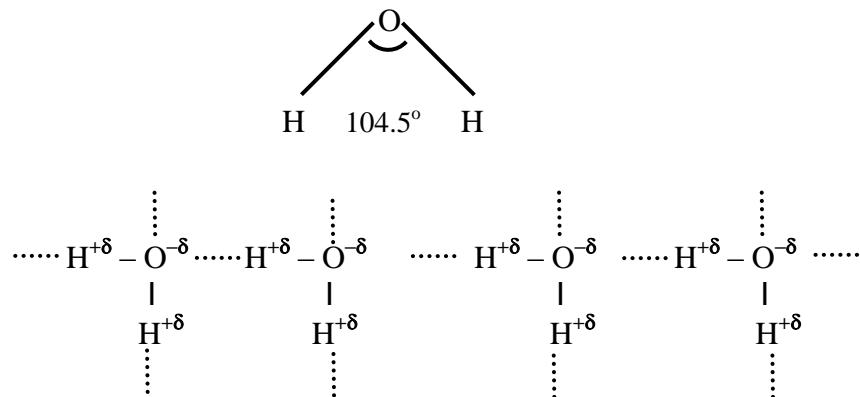
Chemically water is a neutral oxide. The chemical name of water is hydrogen oxide. It acts as both acid as well as base in certain chemical reactions. It is one of the most abundant compounds of oxygen and hydrogen in this planet about 76%. It is vital for life and its excess or shortage is fatal for life. It is 70% by weight in human body and 90% in plant body.

Formula of water:

Initially water was considered an element but *Priestly* in 1776 declared that water is a compound of oxygen and hydrogen. *Morley* in 1895 determined the composition of water by weight, by the reaction of hydrogen gas with the oxygen gas in the presence of an electric spark and proved that water is formed by the combination of hydrogen and oxygen in the ratio 1:8 by weight. Similar results are obtained by the electrolytic cleavage of water in the *Hoffman's Voltmeter* that the ratio of hydrogen and oxygen in water is 1:2 by volume. So the formula of water is H_2O .

The valency of hydrogen is '+1' while oxygen is '-2', so logically its formula comes to be H_2O . More over water contains 11.11% hydrogen and 88.89% oxygen. So the formula of water must be H_2O . It has polar covalent bond and shows dipole moment. The bond angle between water molecule is

104.5° and it carries partial positive and partial negative charge resulting in hydrogen bonding that helps to dissolve a variety of substances.



Hydrogen bonding in water molecules

PROPERTIES OF WATER

Following are the properties of water;

i) Physical Properties:

The physical properties of water are: -

1. Pure water is tasteless and colourless liquid.
2. It freezes at 0°C .
3. It boils at 100°C .
4. Its density at 4°C is maximum i.e., 1g/cm^3 .
5. Water shows a very small conductivity.
6. The bond length between O–H is 0.97°A .
7. The bond angle between H–O–H is 104.5° .
8. The water molecules are held together by hydrogen bonding.
9. Water has 33% ionic character and 67% covalent character.
10. Water is an excellent solvent and due to this property it is employed to dissolve a great variety of solids, liquids, and gases.

ii) Chemical properties:

1. Water is dissociated 0.1% at two thousand degree centigrade temperature.

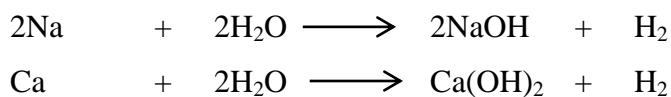
The dissociation increases with the rise of temperature and fall of pressure.



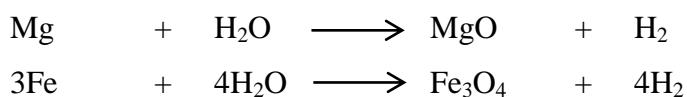
2. Pure water does not conduct electricity. However, when current is passed through water having few drops of acid, it breaks up into two gaseous components, hydrogen and oxygen.



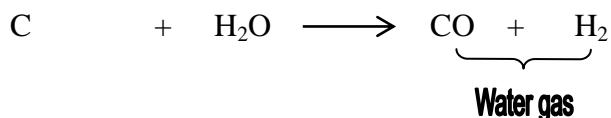
3. Water reacts with alkali metals and alkaline earth metals to give the respective metal hydroxides and hydrogen gas in the cold state.



4. Less reactive metals like magnesium, zinc and iron decompose steam to form metal oxides and hydrogen.



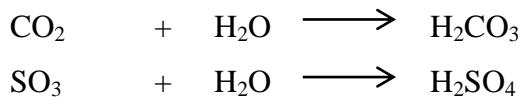
5. When steam is passed over red-hot carbon at 1000°C, a mixture of carbon monoxide and hydrogen known as water gas is formed



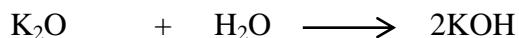
6. Chlorine and water slowly form a mixture of hydrochloric and hypochlorous acids, at ordinary temperature.



7. Water reacts with non-metal oxides to form acids. For example,



8. Water reacts with metal oxides to form bases, e.g.





GENERAL IMPURITIES OF WATER:

Water seldom occurs in pure state owing to its reactivity and universal solvent. There are three types of impurities present in water i.e.,

1. Dissolved impurities
2. Suspended impurities
3. Biological impurities

1. Dissolved Impurities:

These impurities are soluble in water and cannot be observed with the human eye. These may be

- i) Inorganic salts like carbonates, sulphates, halides, and nitrates of heavy metals like Ca, Mg, Al, & Fe, etc. These are responsible for hardness and alkalinity to water.
- ii) Organic matter, volatile or non-volatile if present in excess is undesirable.
- iii) Gases like O₂, N₂, H₂S, SO₂, NO₂, CO₂ and CO. Oxygen and CO₂ are essential for life while the other gases are responsible for odour, increase acidity and cause corrosion problems. The impurity that is hardest to keep out of distilled water is carbon dioxide, which dissolves readily from the atmosphere.

2. Suspended impurities:

These are colloidal impurities present in the water and remain suspended and do not settle down. These includes

- i) Inorganic substances like sand, clay and rock particles.
- ii) Organic matter, like vegetable and animal matter.

3. Biological impurities:

Bacteria, fungi, algae etc. are known as biological impurities which are responsible for colour, odour and turbidity of water and cause disease to

the animals / plants.

Hard water:

The water, that contains dissolved salts like CaCl_2 , CaSO_4 , MgCl_2 and MgSO_4 , and it forms curds and poor lather with soap is called '*hard water*'. Common portable water is an example of hard water.

Soft water:

On the other hand the water, which easily produces lather with the soap, is said to be '*soft water*'. Distilled water is an example of soft water.

Causes of water hardness:

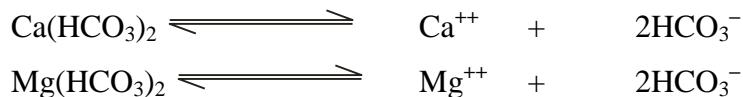
The soluble salts of metals like calcium and magnesium are responsible for hardness of water. It includes bicarbonates, chlorides and sulphates of these metals.

TYPES OF WATER HARDNESS:

1. Temporary water hardness
2. Permanent water hardness

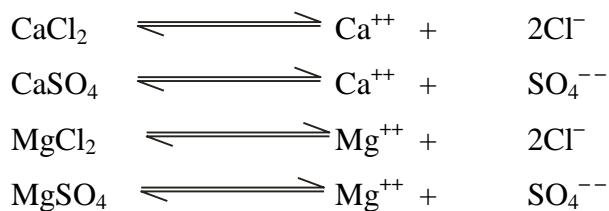
1. Temporary water hardness:

This is due to the presence of bicarbonates of calcium and magnesium in water. These salts are soluble in water and are present in the form of ions as shown below;



2. Permanent water hardness:

This is due to the presence of chlorides & sulphates of calcium and magnesium or any one of these i.e., CaCl_2 , CaSO_4 , MgCl_2 & MgSO_4 .



REMOVAL OF WATER HARDNESS:

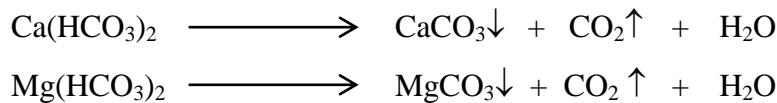
Separate and common methods are used for removal of both types of water hardness. All these methods involve the conversion of a soluble salt into insoluble form and then to remove it either by filtration or sedimentation.

Removal of temporary water hardness:

Following methods are used for the removal of temporary water hardness;

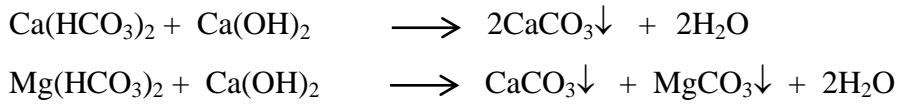
1. By Boiling:

In this method water is boiled to convert soluble bicarbonates to insoluble carbonates which are subsequently removed by filtration. This method is only applied to a limited scale only.



2. Clark's Method:

This method is used to remove hardness on a large scale. A calculated quantity of limewater is added which converts soluble bicarbonates into insoluble carbonates.



REMOVAL OF PERMANENT WATER HARDNESS:

Following methods are being used for the removal of permanent water hardness;

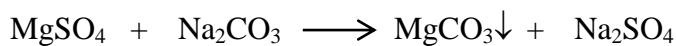
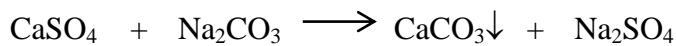
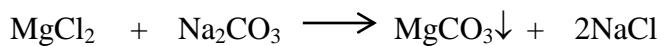
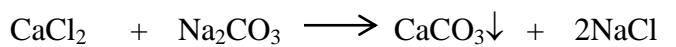
1. Soda ash method
2. By caustic soda

Following are the common methods used for both temporary and permanent water hardness

3. Zeolite or Permutit method
4. Ion exchange process

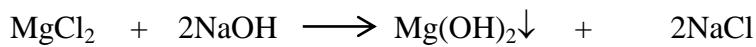
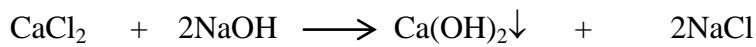
1. Soda ash method:

In this method washing soda is added which converts soluble chlorides and sulphates into insoluble carbonates and are hence removed by filtration.



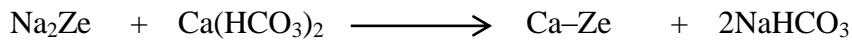
2. By caustic soda:

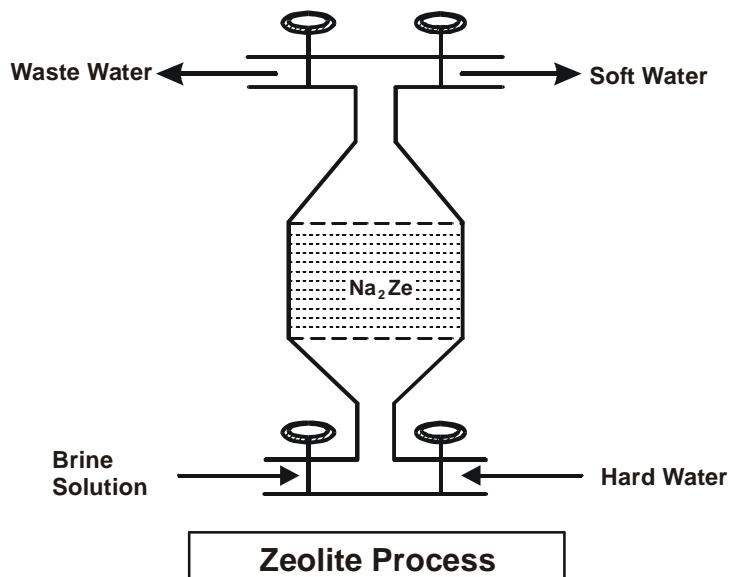
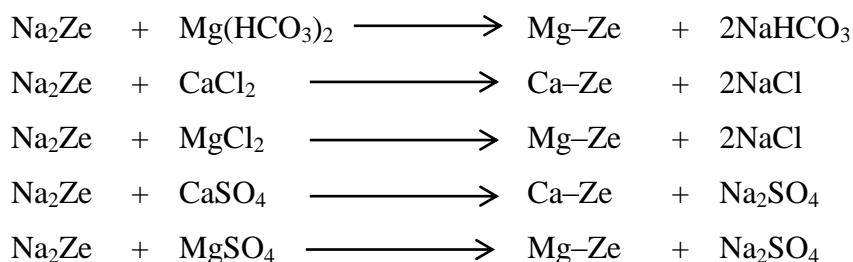
This method is similar to soda ash method but caustic soda is used instead of washing soda, which converts soluble chlorides and sulphates into insoluble hydroxides and are hence removed by filtration.



3. Zeolite or Permutit method:

In this method water is passed through a column filled with sodium zeolite having formula $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$ (Na_2Ze) or generally written as Na_2y where $y = \text{Al}_2\text{Si}_2\text{O}_8 \cdot x\text{H}_2\text{O}$. The column absorbs positive ions of calcium and magnesium to form insoluble calcium zeolite (Ca-Ze) and magnesium zeolite (Mg-Ze), and passes on the sodium ions into the water, which does not cause hardness. This method is used for the removal of both temporary and permanent water hardness.





Regeneration of Zeolite:

Zeolite becomes inactive after long time usage. So treating insoluble calcium zeolite with concentrated brine solution (a saturated solution of sodium chloride is called brine solution) regenerates it.



5. Ion exchange process (See Sea water Desalination at last of this chapter)

MEASUREMENT OF WATER HARDNESS:

Water hardness is measured in terms of CaCO_3 equivalents.

CaCO_3 equivalent can be calculated by the following formula.

$$\text{CaCO}_3 \text{ equivalents} = \frac{\text{Mass of hardness producer}}{\text{Equivalent mass of hardness producer}} \times 50$$

Following four units are used to measure water hardness:

1. Parts per million
2. Milligram per litre
3. Degree Clark
4. Degree French

1. Parts per million (PPM):

The number of parts by weight of CaCO_3 Equivalent present in 1 million (10^6) parts by weight of water is called PPM. So

$$1\text{-part of } \text{CaCO}_3 \text{ in } 10^6 \text{ parts of water} = 1 \text{ PPM}$$

2. Milligram per litre: (mg/L)

The milligrams of CaCO_3 equivalent present in 1-litre of water is called milligram per litre. PPM and mg/L are the same units.

$$\text{As } 1 \text{ litre of water} = 1 \text{ Kg} = 10^6 \text{ parts of water}$$

$$\text{So } 1 \text{ mg/L} = 1 \text{ mg/Kg}$$

$$1 \text{ mg/L} = 1 \text{ PPM}$$

3. Degree Clark: (${}^\circ\text{Cl}$)

The number of parts by weight of CaCO_3 Equivalent present in 70000 parts by weight of water is called Degree Clark. Or the presence of 1 grain of CaCO_3 in 1 gallon of water.

$$1 \text{ Clark} = 1 \text{ grain of } \text{CaCO}_3 \text{ per gallon or 10 pounds of water}$$

$$\text{or } 1 \text{ Clark} = 1 \text{ grain of } \text{CaCO}_3 \text{ in 70,000 grains of water.}$$

4. Degree French (${}^\circ\text{Fr}$):

The number of parts by weight of CaCO_3 equivalent present in 100,000 (one-lakh) parts by weight of water is called Degree French.

$1^{\circ}\text{Fr} = 1$ part of CaCO_3 per 100,000 parts of water
or $1^{\circ}\text{Fr} = 0.1$ PPM

Following is the relation in all units of water hardness: -

$$1^{\circ}\text{Fr} = 0.1 \text{ PPM} = 0.1 \text{ mg/L} = 0.07 \text{ Cl}^{\circ}$$

BOILER FEED WATER:

Water is extensively used in industries like textile, sugar, paper and pharmaceuticals apart from domestic purpose. Most of the water in industries is used for washing and in the production of steam, which is used for heating purposes. Boiler feed water should be free from dissolved impurities. In other words water should be soft rather than hard. If hard water is used as boiler feed water, it results in a number of troubles like;

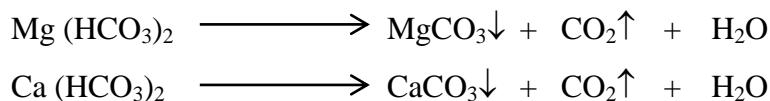
1. Formation of scale
2. Corrosion of the boiler
3. Caustic embrittlement
4. Priming and foaming

1. Formation of scale:

If boiler is feed with continuously hard water, the soluble impurities separate out and settle down in the form of scale. Scales are hard deposits, sticking firmly to the inner walls of the boiler tubes. The impurities that do not settle down but remain in suspended form are called '*sludge*'. The scales are formed by the following ways;

i. Decomposition of Bicarbonates:

Under low pressure the $\text{Mg}(\text{HCO}_3)_2$ & $\text{Ca}(\text{HCO}_3)_2$ decompose into CO_2 gas and MgCO_3 & CaCO_3 , which deposits in the internal walls of the boiler as scale.



ii. Deposit of calcium sulphate:

In high-pressure boilers CaSO_4 , which is sparingly soluble in cold water, precipitates out in super heated water and is the main cause of scale formation in the heated portions of the boilers where it sticks very firmly and is difficult to remove.

iii. Presence of silica:

The presence of silica (SiO_2) in water also produces a firm adherent scale of CaSiO_3 and MgSiO_3 inside the boiler.

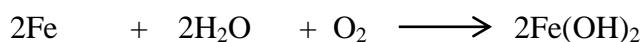
iv. Hydrolysis of magnesium salts:

Dissolved magnesium salts undergo hydrolysis at high temperature inside the boiler, forming magnesium hydroxide precipitate.

**2. Corrosion of boiler:**

The decay of the boiler metal i.e. iron by the chemical or electrochemical attack of the dissolved gases and the acid produced from certain dissolved gases is called corrosion of the boiler. For example

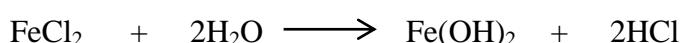
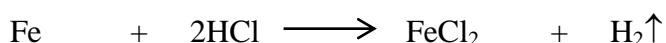
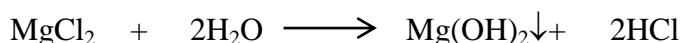
a. Dissolved oxygen is the major cause of corrosion of boiler.



b. Dissolved carbon dioxide produces carbonic acid that stimulates corrosion.

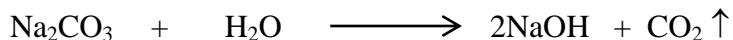


c. Some dissolved salts get hydrolysed to produce certain acids that stimulate boiler corrosion.



3. Caustic embrittlement:

This is the special type of corrosion caused by alkaline water in the boilers. It is partially due to the presence of washing soda that was left during water softening. Its main areas of attack are bends, joints, rivets etc.



4. Priming and foaming:

'Priming' is the process in which the liquid water is carried away along with the steam, also called the wet steam while 'foaming' is the production of persistent foam or bubbles. These are produced by the oily substances. Sometimes these substances can block the boiler tubes and are also responsible for boiler explosions. Priming is controlled by mechanical steam purifier or by slow heating while foaming is controlled by anti foaming chemicals.

Nature of scale:

Chemically all the soluble salts, which are present in the hard water are responsible for scale formation. CaCO_3 is very hard and is the chief ingredient of the scale whereas MgCO_3 , MgCl_2 , CaCl_2 , MgSO_4 , & Mg(OH)_2 forms the soft scale that is sludge.

TREATMENT OF SCALE:

Scales in boiler if once formed are difficult to remove. However to avoid scale formation boiler feed water is treated before its usage in the boiler. There are two types of treatment of scales;

- a. External treatment
- b. Internal treatment

a. External treatment:

This involves the treatment of water before it is fed into the boiler. It involves the same methods that are used for the removal of temporary and permanent water hardness like

- | | |
|-------------------------|-------------------------------|
| 1. Soda ash method | 2. By caustic soda |
| 3. Lime-Soda process | 4. Zeolite or Permutit method |
| 5. Ion exchange process | |

Simply water is purified from all soluble impurities by any one of the above methods, then the soft water used will not cause any harm to the boiler.

b. Internal treatment:

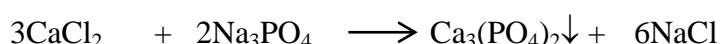
It is the process of treating the water inside the boiler during evaporation to avoid scale formation. This process is also called '*corrective treatment*'. It is basically aimed to remove the defects left in the external treatment. Following are the methods used for internal treatment;

1. Colloidal conditioning;

In this process kerosene oil, glue, tannin etc are used, which are coated over the scale forming substances to form sludge rather than scale. These substances form a protective layer on the inner side of the boiler and thereby preventing the precipitates from sticking to the sides of the boiler. These are then removed by '*blow down process*'. This process is used in low-pressure boilers.

2. Phosphate conditioning:

In this process some phosphate compounds are added in the high-pressure boilers to avoid scale formation. For example the addition of sodium phosphate forms non-adherent, easily removable and soft sludge of calcium & magnesium, which are subsequently removed by '*blow down process*'.

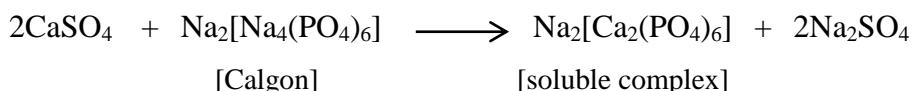


3. Carbonate conditioning:

In this process the addition of washing soda prevents the formation of CaSO_4 as scale in low-pressure boilers to form sludge of CaCO_3 , which is removed by the '*blow down process*'.

4. Calgon conditioning:

In this process calgon (sodium hexa-meta-phosphate) is added to form a soluble complex compound with CaSO_4 , which do not settle down to form scale and hence removed by the blow down process.

**SEWAGE TREATMENT:**

Sewage water is the wastewater from cities, toilets, kitchens, urinals etc. Sewage water was directly dumped into the canals or rivers in the past. Now there should be an effective disposal system for the sewage water to avoid water pollution. Prevention of water pollution is most obligatory because it is directly responsible for soil infertility and indirectly for air pollution. Removing all types of suspended matter from the sewage and industrial wastewater can only prevent water pollution. The treatment of the sewage water depends upon the quantity of the suspended solid matter and the BOD [bio-oxygen demand] of the sewage water. The sewage water treatment or its purification is carried out in the following steps:

A. Primary Treatment:

Sewage water is passed through stainers to remove 30 to 60% insoluble suspended impurities. It removes the suspended solids from the wastewater either by sedimentation i. e., to left water for several days to allow suspended matter to settle down or by coagulating waste-water with chemicals like alums, ferric chloride etc.

B. Secondary Treatment:

Here the wastewater is passed through macro filters, which are made up of stone beds, coke, gravel and silica. The air is also passed through the

filtered water under pressure that kills microbes. The residue obtained is used as organic fertiliser.

Modern treatment:

In this method oxygen is used instead of air. It is cheaper method and the plant is smaller in size. More over the amount of sludge produced is less and also filthy smell is no more there.

C. Tertiary Treatment:

It is the final step for the removal of all types of suspended matter from the wastewater with the help of micro stainers. Inorganic and organic matter is removed by evaporation or by treating with metallic hydroxides like Al(OH)_3 . More over microbes and other biological matter is destroyed by the passage of chlorine. Minute particles are sometimes separated by osmosis.

After treating sewage water in these three stages it is fit for disposal in canals and rivers, as it contains no harmful substances. Moreover the solid waste collected from the sewage water in all these stages is used as fertiliser, buried in the soil or burnt depending upon its nature.

SEA WATER DESALINATION:

Sea water is the most impure form of natural water available in this planet as it contains more than 3.5% dissolved salts. In some parts of the world and also in Pakistan, Karachi seawater is used for domestic purpose. It also contains a number of microbes that are injurious to health. The seawater desalination is carried out in the following steps:

1. Sedimentation & Filtration
2. Desalination
3. Sterilisation

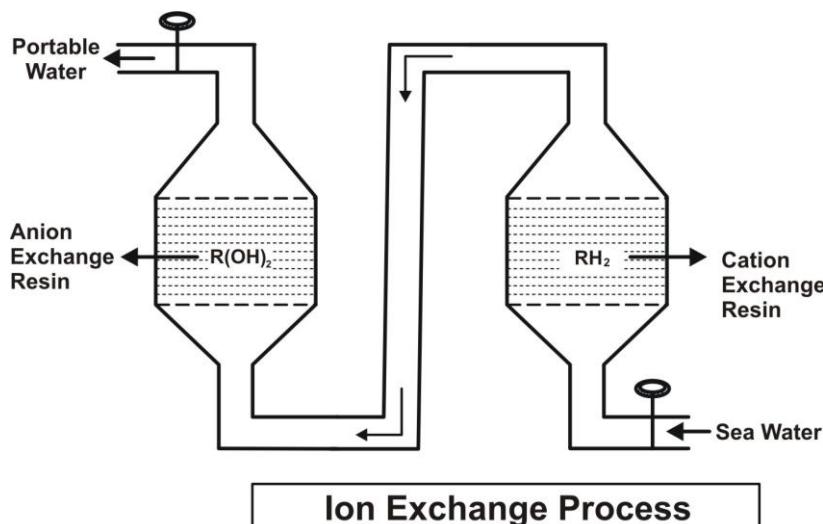
1. Sedimentation & Filtration:

The seawater is collected in large tanks where it is allowed to stand for several hours to allow suspended impurities to settle down. Sometimes

coagulating chemicals like alum, ferric chloride etc is also used. The suspended impurities are then removed by filtering through sand filters.

2. Desalination:

The soluble impurities i.e., salts are removed by ion exchanger resins. The seawater is passed through a series of cation exchanger and anion exchanger resins to remove soluble salts. This process is same as were used for the removal of permanent hardness of water.

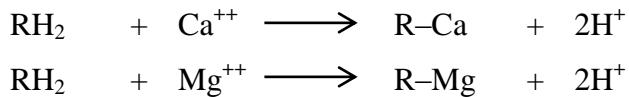


This method is also known as “*Desalting, Deionisation or Demineralisation Process*”. Ion exchange resins are of two types;

- i. Cation exchange resins
- ii. Anion exchange resins

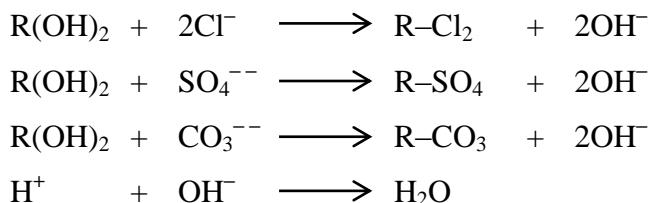
i. Cation exchange resins:

The seawater is initially passed through cation exchange resin (RH_2) which removes only cations and as a result H^+ is liberated.

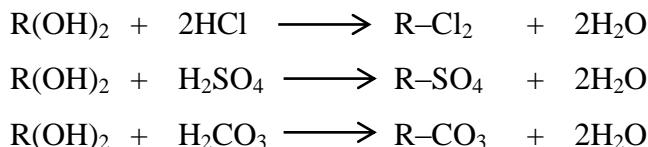


ii. Anion exchange resins:

The water is then passed through the Anion exchange resins $[R(OH)_2]$ which removes the anions and as a result OH^- ions are given out , which combines with H^+ ions to form water.



The H^+ ions given out by the cation exchange resins actually combines with the anions like Cl^- , SO_4^{2-} , HCO_3^- , CO_3^{2-} etc. present in water to form their respective acids. So the above reactions of anion exchanger can also be written as;

**3. Sterilisation of water:**

To make water free from microbes and fit for human consumption is referred to as sterilisation of water. This process is also known as '*disinfection of water*'. This process is very crucial as the contaminated water may cause health hazards and diseases. After the desalination of seawater, sterilisation is obligatory.

OBJECTIVE QUESTIONS**Q. Give answer to the following short questions:**

- What is the chemical name of water and which type of oxide is it?

2. Write the names and formula of the salts responsible for temporary water hardness?
3. What is the difference between soft and hard water?
4. Write the names and formula of the salts responsible for permanent water hardness?
5. Give two chemical properties water.
6. Give the formula of Zeolite.
7. Give four physical properties of water.
8. Which salts are responsible for scale and sludge formation?
9. Describe carbonate conditioning of boiler scale treatment.
10. Describe Soft water.
11. What is the abbreviation for BOD?

Q. Select the correct answer from the following MCQ's.

1. The ratio of water on our planet as compared to dry land is
 - (a) 75%
 - (b) 76%
 - (c) 77%
 - (d) 78%
2. The percentage of hydrogen to oxygen in water is:
 - (a) 11.11 & 88.89
 - (b) 12 & 88
 - (c) 13 & 87
 - (d) 10 & 90
3. The bond angle between H–O–H is
 - (a) 104.4°
 - (b) 104.2°
 - (c) 104.3°
 - (d) 104.5°
4. The most and readily soluble gas in water is
 - (a) CO_2
 - (b) CO
 - (c) O_2
 - (d) N_2
6. The water used in the boiler is
 - (a) Heavy water
 - (b) hard water
 - (c) soft water
 - (d) common water

- 7.** **1 PPM is equal to mg/L**

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

8. **The isolation of salts from the sea water is called**

(a) salinity (b) salivation
(c) salts (d) desalination

9. **The chemical name of water is**

(a) hydroxide (b) hydrogen oxide
(c) hydrogen peroxide (d) no one

10. **The alternate name for the zeolite method is**

(a) Ion exchange process (b) Deionisation process
(c) Demineralisation Process (d) Permutit method

11. **The formula of cation exchange resin is**

(a) RH₂ (b) RH₃
(c) R(OH)₂ (d) R(OH)₃

12. **The insoluble impurities that sticks firmly to the inner walls of the boiler tubes is called**

(a) scale (b) sludge
(c) silica (d) all three

13. **The insoluble impurities that remain suspended in the inner walls of the boiler tubes and do not settle down are called**

(a) scale (b) sludge
(c) silica (d) all three

14. **used for the internal treatment of scales in boiler**

(a) Colloidal conditioning (b) Phosphate conditioning
(c) Calgon conditioning (d) all three

15. **Prevention of water, is most obligatory because it is directly responsible for soil infertility and indirectly for air pollution**

LONG QUESTIONS

1. Describe the chemical nature of water
 2. Discuss the formula of water
 3. Describe the general impurities present in water
 4. Explain the causes and methods to remove temporary hardness of water

5. Explain the causes and methods to remove permanent hardness of water
6. Describe scales for measurement hardness of water.
7. Describe the formation and nature of scale in boiler feed water
8. Explain the methods for the treatment of scale in boiler feed water
9. Explain the sewage water treatment.
10. Explain the desalination of sea water.



Chapter 7

Acids, Bases & Salts

Course contents **2 Hrs**

- 7.1 Definitions with examples
- 7.2 Properties, their strength, Basicity & acidity
- 7.3 Salts and their classification with examples
- 7.4 pH value and scale

Learning Outcomes:

After studying this lesson the students would be able to:

- 7.1 Define acids and bases and salts with examples
- 7.2 State general properties of acids and bases
- 7.3 Differentiate between acidity and basicity
- 7.4 Define salts, state their classification with examples
- 7.5 Explain pH value of solution and pH scale

INTRODUCTION

The word Acid is derived from a Latin word “**Acidus**” that means ‘**Sour**’. The Acetic Acid (CH_3COOH) was the first acid known to man. Jabir Bin Hayan, a well known Muslim chemist (father of chemistry) prepared Nitric acid (HNO_3), Hydrochloric acid (HCl) and Sulphuric acid (H_2SO_4). In 1787, Lavoisier named the following Oxides i.e., CO_2 and SO_2 as Acids, as their water solutions gave acidic solutions which change blue litmus to red. In industry Acids are used to make many products like dyes, paints, detergents,

fertilizer, drugs, & explosives etc. Citric acid and Tartaric acids are naturally occurring organic acids found in lemon and grapes respectively.

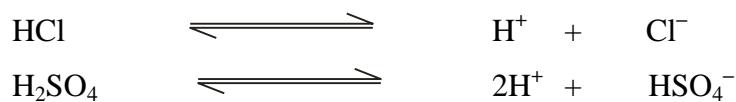
Similarly the word alkali (a soluble base) was derived from the Arabic word “**al-qili**” which means the ‘**ashes**’ of the plants. Alkali appears to have opposite of the acids and it has a bitter taste. Like acids bases are very common in our daily life. They have slippery touch, and turn red litmus to blue. They are used to make soap, detergents, & bleaching powder. They are used in alkaline batteries.

Salts are ionic compound, generally formed by neutralization reaction of an acid with base. Salts are used in industry for making adhesive, plastic and glass.

Definition of Acid:

1. According to Arrhenius Concept:

“*Acids are those compounds which give hydrogen ions when dissociate in aqueous solution*”. For example Hydrochloric acid (HCl), Sulphuric acid (H_2SO_4).



2. According to Lowry & Bronsted Concept:

Acids are those compounds which donate or tend to donate a proton H^+ to another compound. For example CH_3COOH , HCl, HCN etc are acids as they can donate a proton. So an acid is a proton ‘**donor**’.

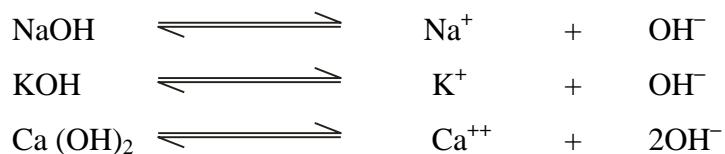
3. According to Lewis Concept:

According to this concept, “*an acid is a species (molecule or ion) which can accept a pair of electrons*”. Like AlCl_3 , BF_3 , & H_3O^+ etc. These Lewis acids are deficient of electrons so these are called ‘**electrophile**’ or electron lovers.

Definition of Bases:

1. According to Arrhenius Concept:

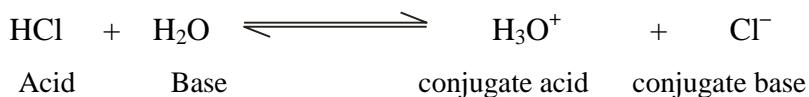
“Bases are those compounds which give hydro oxide (OH^-) ions when dissociate in aqueous solution”. For example Sodium hydroxide (NaOH), Potassium hydroxide (KOH), & Calcium hydroxide [Ca(OH)_2], are bases as they give hydro oxide ions on dissociation.



2. According to Lowry & Bronsted Concept:

Bases are those compounds which accept or tend to accept a proton. For example NH_3 , H_2O etc are bases as they can accept a proton. So a base is a proton ‘**acceptor**’.

When HCl is dissolved in water then HCl acts as an acid while H_2O act as a base as shown.

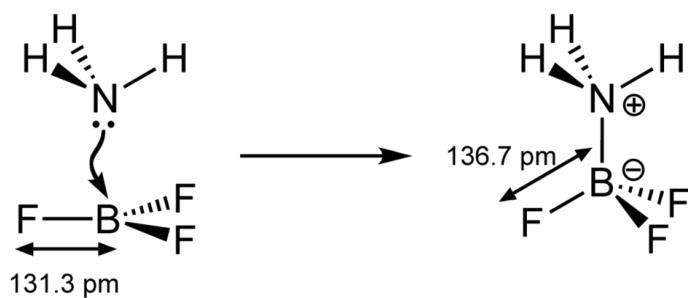


3. According to Lewis Concept:

“A base is defined as a species (molecule or ion) which can donate a pair of electrons”. Like OH^- , F^- , CaO & NH_3 etc. These Lewis bases have excess of electrons so these are called ‘**nucleophile**’ or nucleus lovers.

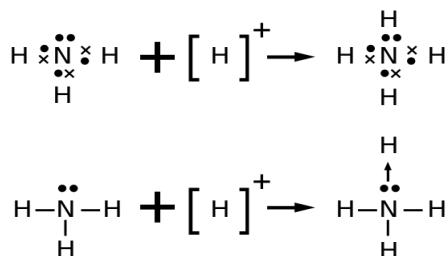
Reaction between NH_3 & BF_3 :

In this reaction ammonia act as Lewis base while boron trifluoride act as Lewis acid.



Reaction between NH₃ & H⁺:

In this reaction ammonia act as Lewis base while H⁺ act as acid.



GENERAL PROPERTIES OF ACIDS:

We will discuss the physical and chemical properties of acids separately;

Physical properties:

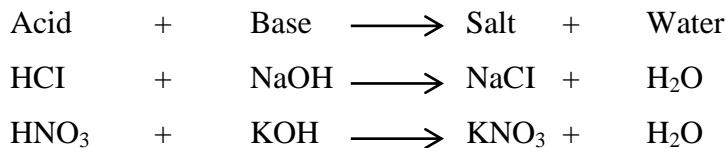
Following are the physical properties of acids:

1. Acids have sour taste.
2. They turn blue litmus to red.
3. They turn yellow solution of methyl orange to red.
4. They are good conductor of electricity.
5. Strong acids destroy fabrics, animal tissues and affect skin.
6. They are corrosive in concentrated form.
7. They yield H⁺ ions in aqueous solution.
8. They can dissolve a variety of substances.

Chemical properties:

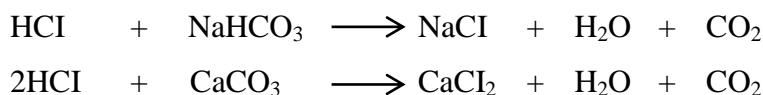
a. Reaction with bases:

Acids react with bases to form salt and water this process is called neutralization.



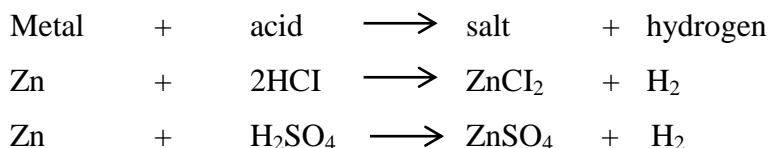
b. Reaction with carbonates and bicarbonates:

Acids react with metallic carbonates and bicarbonates and produce carbon dioxide gas.



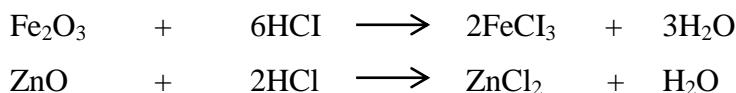
c. Reaction with metals:

Acid react metals and liberates hydrogen gas.



d. Reaction with metal oxides:

Acids react with metal oxides and form salt and water in the same way as with metal hydroxide.



GENERAL PROPERTIES OF BASES:

Physical properties:

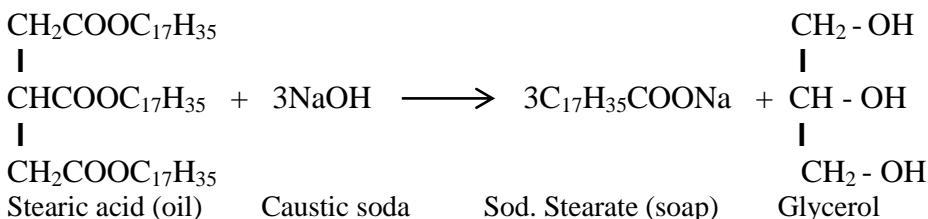
1. Bases have bitter taste.
2. They have a slippery touch.
3. They are conductor of electricity.

4. They turn red litmus to blue.
5. They turn colourless phenolphthalein to pink, methyl orange to yellow and turmeric paper to brown.
6. They damage human skin and animal tissue.
7. They give hydroxyl ions (OH^-) in aqueous solution.
8. Except NaOH & KOH they are non corrosive.

CHEMICAL PROPERTIES:

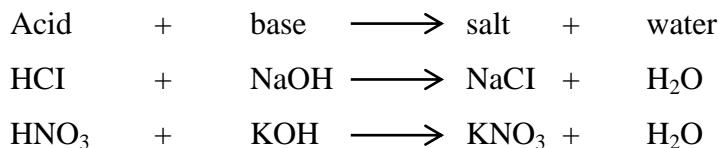
1. Reaction with fats and oils:

Bases react with fats and oils to form soap. This process is called saponification.



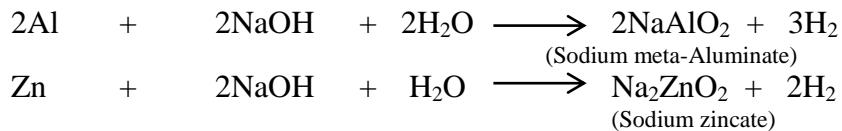
2. Reaction with acids:

Bases neutralise acids to form salt and water.



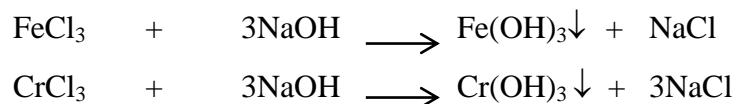
3. Reaction with metals & non-metals:

Bases react with certain metals like tin, zinc, aluminium, etc. and non-metals like silicon, but the reaction is slow at room temperature. For example,



4. Reaction with metallic salt:

Bases react with heavy metal salt and form hydroxides.



Strength of Acid and Base:

Strong Acids:

Those acids which completely ionize in water are called strong acids
e.g. H_2SO_4 , HNO_3 , HCl etc,

Weak Acids:

Those acids which incompletely ionize in water are called weak acids
e.g. CH_3COOH & H_2CO_3 .

Strong Bases:

Those bases which completely ionize in water are called strong bases
e.g. NaOH & KOH .

Weak Base:

Those bases which partially ionize in water are called weak bases e.g.
 Fe(OH)_3 & Co(OH)_2 . Water soluble bases are also called alkalies, like KOH and NaOH . Every alkali is a base but every base is not an alkali.

Acidity of bases:

The acidity of bases is defined as “*the number of replaceable or ionisable hydroxyl ions (OH^-) present in one molecule of a base*”. It represents to the extent to which the number of hydroxyl ions is liberated in the solution by the base. If a base has one ionisable hydroxyl ion (OH^-) in its molecule then it is called monoacidic base, for two ionisable hydroxyl ions (OH^-) diacidic base and for three hydroxyl ions (OH^-), it is called triacidic base.

ACIDITY OF BASES

S.#	Bases	Formula	Acidity
1.	Sodium hydroxide	NaOH	Monoacidic base
2.	Potassium hydroxide	KOH	Monoacidic base

3.	Ammonium hydroxide	NH_4OH	Monoacidic base
4.	Barium hydroxide	$\text{Ba}(\text{OH})_2$	Diacidic base
5.	Calcium hydroxide	$\text{Ca}(\text{OH})_2$	Diacidic base
6.	Iron hydroxide	$\text{Fe}(\text{OH})_3$	Triacidic base
7.	Aluminium hydroxide	$\text{Al}(\text{OH})_3$	Triacidic base

Basicity of acids:

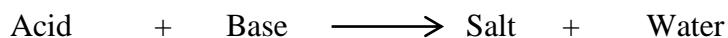
Basicity of acids is defined as the “*the number of replaceable or ionisable hydrogen ions (H^+) present in one molecule of an acid*”. It represents to the extent to which the number of hydrogen ions is liberated in the solution by the acid. If an acid has one ionisable hydrogen ion (H^+) in its molecule then it is called monobasic acid, for two ionisable hydrogen ions (H^+) dibasic acids and for three ionisable hydrogen ions (H^+), it is called tribasic acids.

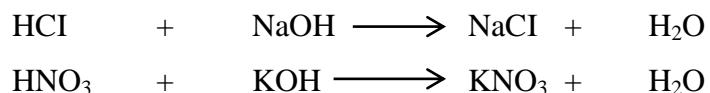
BASICITY OF ACIDS

S.#	Acid	Formula	Basicity
1.	Acetic acid	CH_3COOH	Monobasic acid
2.	Formic acid	HCOOH	Monobasic acid
3.	Nitric acid	HNO_3	Monobasic acid
4.	Hydrocyanic acid	HCN	Monobasic acid
5.	Hydrochloric acid	HCl	Monobasic acid
6.	Hydrogen sulphide	H_2S	Dibasic acid
7.	Oxalic acid	$\text{H}_2\text{C}_2\text{O}_4$	Dibasic acid
8.	Sulphuric acid	H_2SO_4	Dibasic acid
9.	Carbonic acid	H_2CO_3	Dibasic acid
10.	Boric acid	H_3BO_3	Tribasic acid
11.	Phosphoric acid	H_3PO_4	Tribasic acid

SALTS:

When an acid reacts with a base, both of them loose their properties with the formation of a new substance along with water is called salt. For example NaCl , KI , CuSO_4 , KNO_3 etc are salts.





CLASSIFICATION OF SALTS:

Following are the six classes of salts;

- | | |
|------------------|------------------|
| 1. Acidic salts | 2. Basic salts |
| 3. Neutral salts | 4. Double salts |
| 5. Mixed salts | 6. Complex salts |

1. Acidic salts:

These salts are acidic in nature and turn blue litmus to red. These salts are obtained by the partial displacement of hydrogen atoms of an acid.

Examples:

- | | | |
|----------------------------------|------------------------|-------------------------|
| (i) CaHPO_4 , | (ii) KHSO_4 , | (iii) AlCl_3 , |
| (iv) NaH_2PO_4 , | (v) NaHSO_4 | |

2. Basic salts:

These salts are basic in nature and turn red litmus to blue. These salts are obtained by the partial displacement of hydroxyl group (OH) of a base.

Example:

- | | | |
|--|---------------------------------------|--|
| (i) $\text{Ca}(\text{OH})\text{Cl}$ | (ii) $\text{Cu}(\text{OH})\text{Cl}$ | (iii) $\text{Zn}(\text{OH})\text{Cl}$ |
| (iv) $\text{Bi}(\text{OH})_2\text{NO}_3$ | (v) $\text{Pb}(\text{OH})\text{NO}_3$ | (vi) $\text{Pb}(\text{OH})\text{CH}_3\text{COO}$ |

3. Neutral salts:

These salts are neutral in nature and have no affect on litmus paper. These are obtained by the complete neutralisation of an acid with a base. These salts have neither replaceable hydrogen atoms nor hydroxyl group

Example:

- | | | |
|-------------------------------|----------------------|--|
| (i) NaCl | (ii) CuSO_4 | (iii) Na_3PO_4 |
| (iv) NH_4NO_3 | (v) KMnO_4 | (vi) $\text{K}_2\text{Cr}_2\text{O}_7$ |

4. Double salts:

These salts are formed by the combination of two simple salts. These salts usually have common negative radicals but different positive radicals. Upon crystallization from the mixture of equimolar saturated solution of two salts double salts are obtained.

Examples:

- | | | |
|------|--|---------------|
| i) | $\text{Fe}_2(\text{SO}_4)_3 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ | (Ferric alum) |
| ii) | $\text{K}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$ | (Potash alum) |
| iii) | $\text{Cr}_2(\text{SO}_4)_3 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 24\text{H}_2\text{O}$ | (Chrome alum) |
| iv) | $\text{FeSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ | (Mohr's salt) |

5. Mixed salts:

These salts contain more than one acidic or basic radicals. These salts have either two positive and one negative ion or two negative and one positive ion.

Examples:

a) Mixed salts having two positive and one negative ion:

- | | | |
|--------------------------------|---------------------------------|-------------------------|
| (i) NaKSO_4 | (ii) NH_4NaSO_4 | (iii) NaCaPO_4 |
| (iv) MgH_4CO_4 | (v) NH_4CaPO_4 | (vi) KHSO_4 |

b) Mixed salts having one positive and two negative ions:

- | | | |
|---------------------------------------|---------------------------------------|---|
| (i) $\text{Ca}(\text{Cl})\text{NO}_3$ | (ii) $\text{Ca}(\text{OCl})\text{Cl}$ | (iii) $\text{Ca}(\text{OH})\text{Cl}$, |
| (iv) $\text{Mg}(\text{OH})\text{Br}$ | (v) $\text{Pb}(\text{Cl})\text{NO}_3$ | (vi) $\text{Ba}(\text{OH})\text{Cl}$ |

6. Complex salts:

These salts on dissociation give a simple cation (positive ion) and a complex anion (negative ion).

Examples:

- | | | |
|-----|--------------------------------------|--------------------------|
| i. | $\text{K}_4[\text{Fe}(\text{CN})_2]$ | (potassium ferrocyanide) |
| ii. | $\text{K}_3[\text{Fe}(\text{CN})_6]$ | (potassium ferricyanide) |



pH and pH scale.

pH means the power of hydrogen. In 1909 Sorenson defined pH as '*the negative logarithm of the hydrogen ion concentration' in acidic solution.*' The scale that is used to measure the strength of an acid or base is called pH scale. Mathematically pH can be written as.....

$$\text{pH} = -\log [\text{H}^+]$$

Where $[\text{H}^+]$ is the hydrogen ion concentration. Similarly 'pOH' of the solution can be defined as '*the negative logarithm of the hydroxyl ion concentration in a basic solution*'. Mathematically pOH can be written as.....

$$\text{pOH} = -\log [\text{OH}^-]$$

Where $[\text{OH}^-]$ is the hydroxyl ion concentration.

Basis for the pH scale:

The concentration of hydrogen ion $[\text{H}^+]$ in pure water is the basis of pH scale. Water is a weak electrolyte and partially dissociates into its ions.



According to law of mass action,

$$K_c = \frac{[\text{H}^+][\text{OH}^-]}{[\text{H}_2\text{O}]}$$

$$\text{or } K_c[\text{H}_2\text{O}] = [\text{H}^+][\text{OH}^-]$$

because the concentration of water is almost constant. Instead of $K_c[\text{H}_2\text{O}]$ we can write K_w . Therefore,

$$K_w = [\text{H}^+][\text{OH}^-]$$

Where '**Kw**' is the dissociation constant for water and its value is 10^{-14} 24°C.

So

$$[\text{H}^+][\text{OH}^-] = 10^{-14}$$

Taking log on both sides

$$\log[H^+] + \log[OH^-] = \log 10^{-14}$$

Multiply both sides by ‘-1’, we get

$$-\log[H^+] - \log[OH^-] = -\log 10^{-14}$$

Or...

$$-\log[H^+] + \{-\log[OH^-]\} = -\log 10^{-14}$$

Put the values as per definition.

$$pH + pOH = -\log 10^{-14}$$

Take antilog of the right side.

$$pH + pOH = -[-14]$$

$$pH + pOH = 14$$

This means that the sum of pH and pOH is 14. As one molecule of water give one H^+ ion and one OH^- ion therefore we can write.

$$pH = pOH$$

Now above equation can be written as

$$pH + pH = 14$$

$$2pH = 14$$

$$pH = 7$$

Similarly it can be shown that $pOH = 7$.

Water is neutral by nature. Every neutral solution has seven pH. This is the base of pH scale. According to pH scale....

- A solution whose pH is 7 will be neutral.
- A solution whose pH is less than 7 will be acidic.
- A solution whose pH is greater than 7 will be basic.
- A solution whose pH is 6 will be weak acid.
- A solution whose pH is 8 will be weak base.

For various H^+ ion concentrations, the values of pH & pOH are given below:

pH SCALE

S.#	[H ⁺]	pH	POH	Nature of solution
1.	10 ⁰	0	14	Strongly acidic
2.	10 ⁻¹	1	13	
3.	10 ⁻²	2	12	
4.	10 ⁻³	3	11	Weakly acidic
5.	10 ⁻⁴	4	10	
6.	10 ⁻⁵	5	9	
7.	10 ⁻⁶	6	8	Weakly basic
8.	10 ⁻⁷	7	7	→ Neutral
9.	10 ⁻⁸	8	6	
10.	10 ⁻⁹	9	5	
11.	10 ⁻¹⁰	10	4	Strongly basic
12.	10 ⁻¹¹	11	3	
13.	10 ⁻¹²	12	2	
14.	10 ⁻¹³	13	1	Strongly basic
15.	10 ⁻¹⁴	14	0	

OBJECTIVE QUESTIONS**Q. Give answer to the following short questions:**

1. Give two definition of acid with example.
2. Write four physical properties of acids?
4. Define double salts. Write formula with one example.
3. What is Basicity? Write formulas of one dibasic acid?
5. Write two chemical properties of acids.
6. Define monoacidic base with one example.
7. What are weak acids? Give two examples.
8. Give two definition of base with example.
9. Define pH.

10. What are salts? Name their different types.
11. Write two chemical properties of bases.
12. Define acidity. Give an example.

Q. Select the correct answer from the following MCQ's.

1) The bases give..... ions in water

- | | |
|------------------|----------------------------|
| (a) H^+ | (b) OH^- |
| (c) H^- | (d) H_3O^+ |

2) Which one is a Lewis acid?

- | | |
|-------------------|-------------------|
| (a) F^- | (b) OH^- |
| (c) NH_3 | (d) BF_3 |

3) Which one is a Lewis base?

- | | |
|-------------------|----------------------------|
| (a) NH_3 | (b) H_3O^+ |
| (c) BF_3 | (d) AlCl_3 |

4) The process in which base reacts with oil and form soap is called.....?

- | | |
|--------------------|--------------------|
| (a) Halogenation | (b) Saponification |
| (c) Neutralization | (d) Oxidation |

5) The basicity of CH_3COOH is.....?

- | | |
|-------|-------|
| (a) 1 | (b) 2 |
| (c) 3 | (d) 4 |

6) The acidity of sodium hydro oxide is.....

- | | |
|-------|-------|
| (a) 4 | (b) 2 |
| (c) 3 | (d) 1 |

7) Which one is alkali?

- | | |
|------------------------------|------------------------------|
| (a) KOH | (b) $\text{Cu}(\text{OH})_2$ |
| (c) $\text{Al}(\text{OH})_3$ | (d) $\text{Ba}(\text{OH})_2$ |

8) Alum is an example of....

- | | |
|-------------|------------|
| (a) Complex | (b) Double |
| (c) Acidic | (d) Basic |

9) The pH of pure water is....

10) The solution having pH six is called....

11) pH is equal to....

12) The number of ionizable hydrogen atoms present in a acid molecule is called it's.....

13) According to Lewis concept, an acid.....

14) KH_2PO_4 issalt.

15) The pH range of a basic solution is

16) How many water molecules are in the crystal of copper sulphate molecule (CuSO_4)?

17) The nature of solution having pH more than seven will be

- (a) Neutral (b) Acidic

18) Which one is a double salt?

- (a) $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (b) $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$
(c) Na_2SO_4 (d) $\text{K}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3$

19) What will be the effect of mixing more water in acidic solution.....

20) Which one has slippery touch?

LONG QUESTIONS

- Q. Define acid and base with examples.
 - Q. State general properties of acid.
 - Q. State general properties of bases.
 - Q. Define salts, give their classification with examples.
 - Q. Define pH and describe pH scale.



Chapter 8

Oxidation & Reduction

Course Contents **2 Hrs**

- 8.1 The process with examples.
- 8.2 Oxidising and Reducing agents.
- 8.3 Oxides and their classification.

Learning Outcomes:

After learning this chapter the students would be able to:

- 8.1 Define oxidation
- 8.2 Illustrate the oxidation process with examples
- 8.3 Define reduction
- 8.4 Explain the reduction process with examples
- 8.5 Define oxidizing & reducing agents and give at least six examples of each
- 8.6 Define oxides
- 8.7 Classify the oxides and give examples

INTRODUCTION:

The *addition of oxygen* in an element or compound is called oxidation while the *removal of oxygen* from a compound is called reduction. It is obvious that the process of oxidation and reduction takes place side by side in most of the chemical reactions. On one side substances are reduced and on the other side these are oxidised. So all types of chemical reactions in which the process of oxidation and reduction takes place simultaneously are collectively called as “*Redox Reactions*”. Those substances or chemicals that help to carry

out the process of oxidation & reduction are called *oxidising and reducing agents* respectively. The apparent charge on any species in a molecule or compound is called oxidation number.

OXIDATION	REDUCTION
<p>1. Addition of oxygen:</p> <p>The <i>addition of oxygen</i> in an element or compound is called oxidation. For example</p> $\begin{array}{l} \text{C} + \text{O}_2 \longrightarrow \text{CO}_2 \\ 2\text{Mg} + \text{O}_2 \longrightarrow 2\text{MgO} \\ 2\text{Ca} + \text{O}_2 \longrightarrow 2\text{CaO} \end{array}$	<p>1. Removal of oxygen:</p> <p>The <i>removal of oxygen</i> from a compound is called reduction. For example</p> $\begin{array}{l} \text{Fe}_2\text{O}_3 + \text{H}_2 \longrightarrow 2\text{FeO} + \text{H}_2\text{O} \\ 2\text{CuO} + \text{C} \longrightarrow 2\text{Cu} + \text{CO}_2 \\ \text{CuO} + \text{H}_2 \longrightarrow \text{Cu} + \text{H}_2\text{O} \end{array}$
<p>2. Removal of hydrogen:</p> <p>The <i>removal of hydrogen</i> from a compound is called oxidation. For example</p> $\begin{array}{l} \text{Ca} + 2\text{HCl} \longrightarrow \text{CaCl}_2 + \text{H}_2 \\ \text{Zn} + 2\text{HCl} \longrightarrow \text{ZnCl}_2 + \text{H}_2 \\ \text{Mg} + \text{H}_2\text{SO}_4 \longrightarrow \text{MgSO}_4 + \text{H}_2 \end{array}$	<p>2. Addition of hydrogen:</p> <p>The <i>addition of hydrogen</i> in an element or compound is called reduction. For example</p> $\begin{array}{l} \text{N}_2 + 3\text{H}_2 \longrightarrow 2\text{NH}_3 \\ \text{H}_2 + \text{I}_2 \longrightarrow 2\text{HI} \\ \text{H}_2 + \text{S} \longrightarrow \text{H}_2\text{S} \end{array}$
<p>3. Removal of electrons:</p> <p>The <i>removal of electrons</i> from an element or ion is called oxidation. For example</p> $\begin{array}{l} \text{Fe}^{\circ} \longrightarrow \text{Fe}^{++} + 2\text{e}^{-} \\ \text{Fe}^{++} \longrightarrow \text{Fe}^{+++} + 1\text{e}^{-} \\ \text{Sn}^{\circ} \longrightarrow \text{Sn}^{++} + 2\text{e}^{-} \\ \text{Sn}^{++} \longrightarrow \text{Sn}^{++++} + 2\text{e}^{-} \end{array}$	<p>3. Addition of electrons:</p> <p>The <i>addition of electrons</i> in an element or ion is called reduction. For example</p> $\begin{array}{l} \text{Fe}^{+++} + 1\text{e}^{-} \longrightarrow \text{Fe}^{++} \\ \text{Fe}^{++} + 2\text{e}^{-} \longrightarrow \text{Fe}^{\circ} \\ \text{Sn}^{++++} + 2\text{e}^{-} \longrightarrow \text{Sn}^{++} \\ \text{Sn}^{++} + 2\text{e}^{-} \longrightarrow \text{Sn}^{\circ} \end{array}$

4. Increase in the oxidation number: An increase in the oxidation number of an atom as a result of losing electrons is called oxidation. For example $\begin{array}{l} 2\text{FeCl}_2 + \text{Cl}_2 \longrightarrow 2\text{FeCl}_3 \\ 2\text{CO} + \text{O}_2 \longrightarrow 2\text{CO}_2 \end{array}$	4. Decrease in the oxidation number: A decrease in the oxidation number of an atom as a result of gaining electrons is called reduction. For example $\begin{array}{l} 2\text{FeCl}_3 \longrightarrow 2\text{FeCl}_2 + \text{Cl}_2 \\ 2\text{CO}_2 \longrightarrow 2\text{CO} + \text{O}_2 \end{array}$
5. Addition of an electronegative element: The addition of an electronegative element in a compound is called oxidation. For example $\begin{array}{l} \text{SnCl}_2 + \text{Cl}_2 \longrightarrow \text{SnCl}_4 \\ 2\text{FeCl}_2 + \text{Cl}_2 \longrightarrow 2\text{FeCl}_3 \end{array}$	5. Removal of electronegative element: The removal of electronegative element from a compound is called reduction. For example $\begin{array}{l} 2\text{HgCl}_2 + \text{SnCl}_2 \longrightarrow \text{Hg}_2\text{Cl}_2 + \text{SnCl}_4 \\ 2\text{FeCl}_3 + \text{H}_2 \longrightarrow 2\text{FeCl}_2 + 2\text{HCl} \end{array}$
6. Removal of electropositive element: The removal of electropositive element from a compound is called oxidation. For example $\begin{array}{l} 2\text{KI} + \text{H}_2\text{O}_2 \longrightarrow 2\text{KOH} + \text{I}_2 \\ \text{CuO} + \text{H}_2 \longrightarrow \text{H}_2\text{O} + \text{Cu} \\ 2\text{KF} + \text{H}_2\text{O}_2 \longrightarrow 2\text{KOH} + \text{F}_2 \end{array}$	6. Addition of electropositive element: The addition of electropositive element in a compound is called reduction. For example $\begin{array}{l} \text{HgCl}_2 + \text{Hg} \longrightarrow \text{Hg}_2\text{Cl}_2 + \text{Br}_2 \\ \text{K} + \text{Cl}_2 \longrightarrow 2\text{KCl} \\ \text{CaO} + \text{H}_2\text{O} \longrightarrow \text{Ca}(\text{OH})_2 \end{array}$

OXIDISING AGENTS:

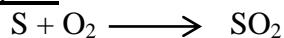
Those elements or compounds which help to carry out the process of oxidation are called *oxidising agents*.

Examples:

Sulphuric acid as an oxidising agent:



In this reaction carbon is oxidised to carbon dioxide. Sulphuric acid help to carry out this oxidation so sulphuric acid is oxidising agent.

Oxygen as an Oxidising agent:

In this reaction Sulphur is oxidized to sulphur dioxide. Oxygen helped to carry out this oxidation, so oxygen is an oxidizing agent.

Some important Oxidising agents

S.#	Name of the oxidising agent	Formula
1.	Oxygen	O_2
2.	Ozone	O_3
3.	Hydrogen per oxide	H_2O_2
4.	Sulphuric acid	H_2SO_4
5.	Nitric acid	HNO_3
6.	Potassium dichromate	$\text{K}_2\text{Cr}_2\text{O}_7$
7.	Mercuric chloride	HgCl_2
8.	Chlorine	Cl_2
9.	Bromine	Br_2
10.	Iodine	I_2
11.	Potassium chlorate	KClO_3
12.	Potassium permanganate	KMnO_4

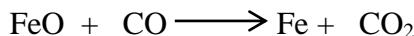
REDUCTION AGENTS:

Those elements or compounds which helped to carry out reduction of some substance are called reducing agents.

Examples:**Carbon as a Reducing agent:**

In this reaction Aluminium oxide is reduced to Aluminium as oxygen is removed from Aluminium oxide. Carbon help to carry out this reaction, so carbon is a reducing agent.

Carbon Monoxide as a Reducing Agent:



In this reaction Ferrous oxide is reduced to Ferrous as oxygen is removed from ferrous oxide. Carbon mono oxide help to carry out this reaction, so carbon mono oxide is a reducing agent.

Some Important reducing agents

S.#	Name of the Reducing agent	Formula
1.	Hydrogen	H ₂
2.	Carbon monoxide	CO
3.	Carbon	C
4.	Stannous chloride	SnCl ₂
5.	Hydrogen iodide	HI
6.	Sodium Sulphite	Na ₂ SO ₃
7.	Aluminium	Al
8.	Ferrous Sulphate	FeSO ₄
9.	Oxalic Acid	C ₂ H ₂ O ₄
10.	Nitrous Acid	HNO ₂
11.	Nascent hydrogen	[H]
12.	Sulphur	S
13.	Sulphur dioxide	SO ₂
14.	Hydro iodic acid	HI

OXIDES:

Oxygen is very reactive gas. It reacts with metals like sodium, potassium, barium, magnesium, aluminium etc as well as with non-metal like carbon, sulphur, phosphorus, nitrogen etc and forms their binary compounds. These binary compounds of oxygen with metals and non-metals are called oxides. For example SO₂, MgO, CO₂, ZnO etc

CLASSIFICATION OF OXIDES: -

On the basis of valence number of oxygen, oxides are classified into following four groups:

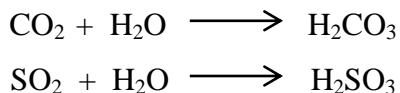
1. Normal oxides
2. per oxide
3. Super oxides
4. Sub oxides

1. Normal Oxides:

Those oxides in which the valence number of oxygen is “-2” are called normal oxides. These are abundant in nature and are identified by their ending name ‘oxide’. These are further divided into following four types: -

a. Acidic oxides:

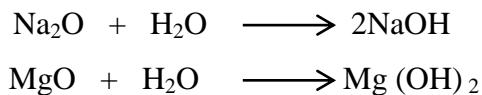
Those oxides which show acidic properties when dissolved in water are called acidic oxides.



Their pH is less than 7. They change blue litmus to red. These are mostly non-metallic oxides. Phosphorus pentaoxide (P_2O_5), Phosphorus trioxide (P_2O_3), Sulphur dioxide (SO_2), Carbon dioxide (CO_2), Nitrogen peroxide (NO_2) and Silicon dioxide (SiO_2) are some important acidic oxides.

b. Basic oxides.

Those oxides which show basic properties when dissolved in water are called basic oxides



Their pH is greater than 7. They change red litmus to blue. These are mostly metallic oxides. Calcium oxide (CaO), Sodium oxide (Na_2O), Magnesium

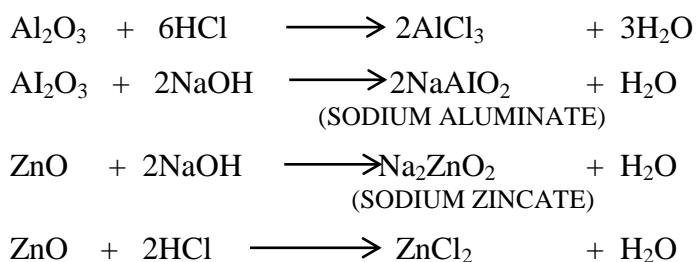
oxide (MgO), Barium oxide (BaO), Potassium oxide (K_2O), and Lithium oxide (LiO_2) are some important basic oxides.

c. Neutral oxides:

Neutral oxides are those oxides that in contact with water produce neither an acid nor a base. Their pH is exactly equal to 7. Their aqueous solution has no effect on blue or red litmus paper. These are mostly non-metallic oxides. Hydrogen oxides (H_2O), Nitric oxide (NO), Carbon monoxide (CO), and Nitrous oxide (N_2O) are some important neutral oxides.

d. Amphoteric oxides:

Those oxides which behave as acids towards bases & bases towards acids are called amphoteric oxides. They possess acidic as well as basic properties.



Their pH may be less or greater than 7. They have no effect on blue or red litmus paper. It means they are dual in nature. Zinc oxide (ZnO), Tin oxide (SnO), Lead oxide (PbO_2) and Aluminium oxide (Al_2O_3) are some important amphoteric oxides.

2. Peroxides:

The valence number of oxygen in peroxides is “-1”. They contain more oxygen than normal oxides. These are powerful oxidising agents. These are identified by their ending name ‘peroxide’. Sodium peroxide (Na_2O_2), Barium peroxide (BaO_2) and Hydrogen peroxide (H_2O_2) are some important peroxides.

3. Super oxides:

The valence number of oxygen in super oxides is “ $-1/2$ ”. Super oxides have an excess amount of oxygen than normal and peroxides. These are identified by their ending name ‘super oxide’. These are mostly metal oxides. These are attracted by magnet. Potassium super oxides (KO_2) and Rubidium super oxides (RbO_2) are some important super oxides.

4. Suboxides:

Sub oxides have less quantity of oxygen than the normal oxides. They are unstable and very few sub oxides are known. These are identified by their ending name ‘suboxide’. Carbon suboxide (C_3O_2) is its example.

Compound oxides:

These are the additional product of two simple oxides. For example Magnetite (Fe_3O_4) is the additional product of Ferrous oxide (FeO) and Ferric oxide (Fe_2O_3). Similarly Red lead (Pb_3O_4) is an additional product of PbO & PbO_2 .

Table showing classification of oxides

S.No	Type of oxide	Valency of oxygen	Examples
1.	Normal oxides		
	Acidic oxides	-2	$NO_2, CO_2, SO_2, P_2O_3, P_2O_5$
	Basic oxides	-2	K_2O, BaO, Na_2O, CaO
	Neutral oxides	-2	NO, CO, N_2O, H_2O
	Amphoteric oxides	-2	PbO_2, Al_2O_3, SnO, ZnO
2.	Peroxides	-1	BaO_2, H_2O_2, Na_2O_2
3.	Super oxide	$-1/2$	RbO_2, KO_2
4.	Sub oxides	Oxygen is less than expected	C_3O_2

OBJECTIVE QUESTIONS

Q. Give answer to the following short questions:

1. Give two definitions of oxidation.
 2. Define oxidising and reducing agent.
 3. Describe redox reaction
 4. What are amphoteric and neutral oxides.
 5. Separate oxidising and reducing agent from the following.
 H_2SO_4 , KMnO_4 , CO , O_3
 6. Define sub oxides and per oxides.
 7. Differentiate between acidity and basic oxides with example.
 8. How Al_2O_3 acts as amphoteric oxide?
 9. What is the oxidation number of oxygen in normal, per, super and sub Oxide?
 10. Name four normal oxide with one example in each case.
 11. What is reduction? Give two examples.

Q. Select the correct answer from the following MCQ's.

- 1) In H_2O_2 the oxidation number of oxygen is

- 2) In Oxidation removal of -----takes place

- a) CO_2 (b) H_2
(c) O_2 (d) SO_2

- 3) In reduction the addition of -----takes place

4) CaO is an example of

5) Na_2O_2 is an example of

6) H₂O₂ is an example of

- (a) Sub oxide (b) Super oxide
(c) Per oxide (d) normal oxide

7) In super oxide the oxidation number of oxygen is

8) C_3O_2 is an example of

9) Which one is oxidizing agent?

10) Which one is reducing agent?

11) ZnO and Al₂O₃ are example of

12) Which one is not per oxide?

13) Which one is normal oxide?

14) Which one is neutral oxide?

15) Which one is not basic oxide?

16) H₂O₂ is a strong

17) Which oxide is not acidic?

18) The formula of carbon sub oxide is

- (a) C_4O_3 (b) C_3O_4
 (c) C_3O_2 (d) C_2O_3

19) ZnO is an example of...

20) KMnO₄ is an.....

- | | |
|--------------------|---------------------|
| (a) Reducing agent | (b) Oxidizing agent |
| (c) Acid | (d) Base |

LONG QUESTIONS

1. Define oxidation. Illustrate the oxidation process with examples.
2. Define reduction? Explain reduction process with examples.
3. Define oxidising and reducing agent and give at least six example of each.
4. Define oxides. Classify the oxides and give examples.
5. What are normal oxides? Discuss their different types with examples.



Chapter 9

Nuclear Chemistry

Course contents	2 Hrs
9.1 Introduction	
9.2 Radioactivity (alpha, beta and gamma rays)	
9.3 Half life process	
9.4 Nuclear reaction and transformation of elements	
9.5 Isotopes and their uses	

Learning outcomes:

After learning this chapter the students would be able to:

- 9.1 Define nuclear chemistry and radioactivity.
- 9.2 Differentiate between alpha, beta and gamma particles.
- 9.3 Explain Half Life process.
- 9.4 Explain at least six nuclear reactions resulting in the transformation of some elements.
- 9.5 State important uses of isotopes.

INTRODUCTION:

The electrons of an atom take part only in a chemical reaction while the nucleus remains silent. Moreover the chemical properties of an element depends upon the number of electrons present in the outer most shell of an atom while the physical properties depend upon the nucleus. The nucleus is circular in shape and lies in the centre of the atom. Moreover its size is very small as compared to the size of the atom.

The exploration of nucleus has gained a lot of popularity because it possesses a lot of stored energy. The nuclear chemistry along with nuclear physics studies the behaviour of nucleus of an atom. Much emphasis is centred on the exploration of nuclear energy obtained by the cleavage of the nucleus in recent decades. It is the need of hour to explore it for our survival, so it is vitally important. The nuclear energy can be utilised for both constructive like nuclear power plants, nuclear energy, & treatment of various diseases, and destructive purposes like atomic bombs, hydrogen bombs etc.

Nuclear Chemistry:

The branch of chemistry that deals with the properties, composition and reactions of the atomic nuclei is called '*nuclear chemistry*'. Or Nuclear chemistry is that branch of chemistry that deals with the structure, composition and properties of the nucleus.

RADIOACTIVITY:

Sir Henry Becquerel in 1896 discovered radioactivity. It is defined as "the spontaneous emission of radiations from certain elements having atomic number more than 82 is called *radioactivity*." The rays thus produced are called radioactive rays. It is an irreversible process and cannot be reverted.

Types of radioactivity:

There are two types of radioactivity;

1. Natural radioactivity
2. Artificial radioactivity

1. Natural Radioactivity:

The process of emission of radiations from the elements having atomic number more than 82 with out the help of any external agency is called '*natural radioactivity*'. The elements that emit radioactive rays are called radioactive elements like Uranium, Thorium, Polonium & Radium etc.

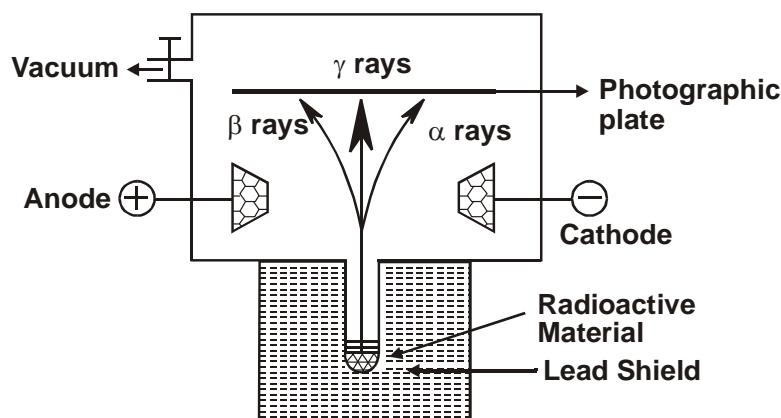
2. Artificial radioactivity:

When an element having atomic number less than 82 is broken down artificially with the help of high-energy particles like neutrons and alpha particles it splits up into smaller nuclei along with the emission of certain radiation. This process is called artificial radioactivity.

Resolution of radioactive rays:

The radioactive rays are resolved by the following method;

Place some radioactive substance in the cavity of the lead block, which is provided with a powerful electric or magnetic field at a very low pressure. The system is also provided with a photographic film at the other end. The system is left for some time and then the film is processed which shows that there are three spots on it. These are actually the spots of the radioactive rays. The rays that travel straight in the middle of the photographic film have no charge and are called gamma or γ -rays. The rays which bend towards the negative pole of the magnetic field, showing positive charge are called alpha or α -rays while the rays which bend towards the positive pole are negative in nature and are called beta or β -rays.



Resolution of radioactivity

RADIOACTIVE RAYS:

There are three types of radioactive rays, namely alpha rays, beta rays and gamma rays.

1. Alpha rays (α -rays):

Following are the general properties of α -rays:

1. Alpha rays are doubly positive charged helium nuclei.
2. These are doubly charged as compared to proton.
3. Their velocity is equal to $\frac{1}{10}$ th to that of light.
4. Their kinetic energy is equal to 3.9 MeV (million electron volts).
5. Their mass is equal to 4 a.m.u.
6. Their ionisation power is high.
7. Their penetration power is low.
8. These bend toward the negative pole in an electric or magnetic field.
9. They affect the photographic plate even in dark.
10. They can produce fluorescence in ZnS plate.
11. They can cause burn and wound in human skin.
12. After travelling a little distance, these are absorbed in the air.
13. These can cause artificial radioactivity.

2. Beta rays (β -rays):

Following are the properties of beta rays:

1. β -rays are fast moving electrons.
2. These are also called '*beta particles*'.
3. They are electronegative in nature.
4. Their e/m ratio is equal to that of electron.
5. Their energy is less than α -rays.
6. Their velocity is nearly equal to that of light.

7. Their penetration power is 100 times more than α -rays.
8. They can also produce fluorescence in the ZnS plate.
9. They also affect the photographic plate.
10. They can cause ionisation in air or gas molecules.

3. Gamma rays (γ -rays):

Following are the major properties of γ -rays:

1. Gamma rays are powerful electromagnetic radiations having no charge and mass.
2. These are not deflected under electric or magnetic field.
3. Their velocity is equal to that of light.
4. They also affect the photographic plate.
5. Their penetration power is very high i.e., 100 times greater than β -rays and 10,000 times more than α -rays.
6. They produce less ionisation in air and gas molecules.
7. These are used for the sterilisation of medical instruments.
8. Gamma rays are more powerful than x-rays.
9. They affect the photographic plate even in dark.
10. They can produce fluorescence in ZnS plate.
11. They can cause burn and wound in human skin.
12. After travelling a little distance, these are absorbed in the air.
13. These can cause artificial radioactivity.

The major difference between α -, β -, and γ -rays is the presence of charge.

The α -rays are positively charged, β -rays are negatively charged while γ -rays are electromagnetic that is neutral in nature. The γ -rays are most powerful, then β -rays and α -rays gradually.

HALF LIFE:

It is the time required to disintegrate half mass of a radioactive

substance. For example if half life of a substance is one day and we have 1 Kg of it then $\frac{1}{2}$ Kg will be left after one day and 250 grams after two days, 125 grams after three days and so on. For example the half life periods of few elements are given below:

HALF LIFE PERIODS

S.#	Name of the element	Symbol	Atomic #	Mass #	Half life period
1.	Radium	Ra	88	226	1590 years
2.	Protactinium	Pa	91	231	3.43×10^4 years
3.	Uranium	U	92	238	4.5×10^9 years
4.	Polonium	Po	84	210	1.6×10^{-4} second
5.	Thorium	Th	90	232	1.39×10^{10} years
6.	Fluorine	F	9	22	4 seconds
7.	Iodine	I	53	131	8 days
8.	Cobalt	Co	27	60	5 years
9.	Carbon	C	6	14	5568 years
10.	Gold	Au	79	198	3 days

NUCLEAR REACTIONS:

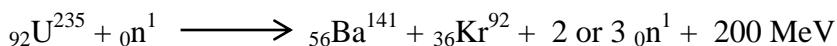
These are the reactions that take place in the nucleus only. The electrons do not play any role in these reactions. Nuclear reactions result changes in the nucleus that may be constructive or destructive. Such reactions are only possible in the nuclear reactors. Following are the types of nuclear reactions:

1. Fission reaction
2. Fusion reaction

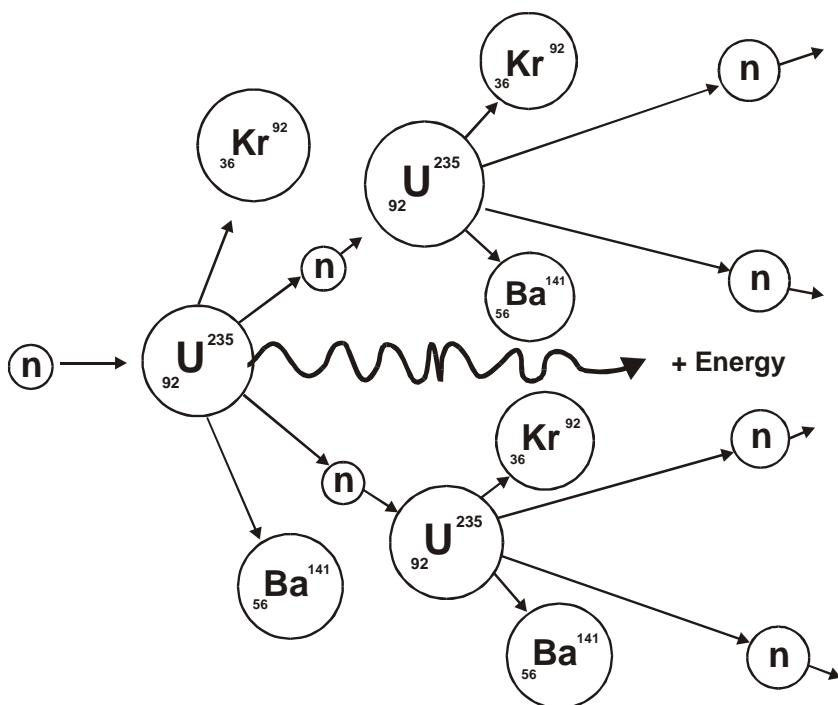
1. Fission reaction:

“Fission” means to ‘*break up*’. So that type of nuclear reaction in which a bulky nucleus is broken down into two or more small fragments, is called nuclear fission reaction. These reactions are always accompanied with the release of huge amount of energy that can be used for both constructive as well as destructive purposes along with neutrons.

For example



It has been estimated that 1 gram of U^{235} emits 8.68×10^7 K.J of energy.

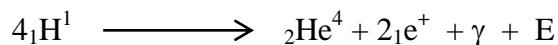


Nuclear fission reaction

2. Fusion reaction:

“Fusion” means to ‘add up’. So that type of nuclear reaction in which two or more lighter nuclei combine or fuse together to form a new heavy nucleus with the release of energy is called nuclear fusion reaction. These reactions are possible only at a very high temperature. So these reactions are also called “Thermo-Nuclear Reactions.”

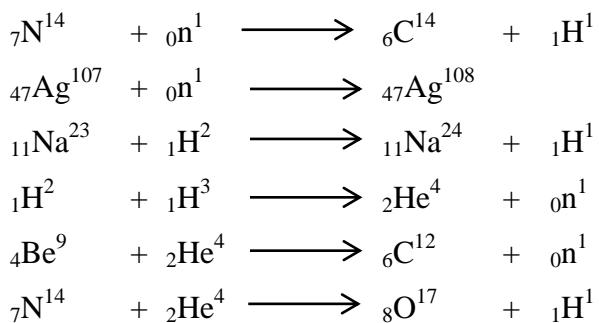
It has been assumed that the fusion reactions are taking place in the sun where 4 hydrogen atoms fuse together to form helium atom with huge energy.



It is calculated that 1gram of hydrogen produces 6.7 MeV of energy in reaction. Hydrogen bomb is the example of nuclear fusion reaction.

TRANSFORMATION OF ELEMENTS:

The conversion of one element into another element in a nuclear reaction that may be fission or fusion with the release of energy is called transformation or transmutation of elements. For example



Radio isotopes:

The atoms of an element having same atomic number but different mass number are called *isotopes*. The isotopes that are unstable and emit radioactive rays are called *radioisotopes*. For example ${}_8\text{O}^{17}$, ${}_6\text{C}^{14}$ & ${}_9\text{F}^{20}$ are radioisotopes of oxygen, carbon and fluorine.

USES OF RADIO ISOTOPES:

1. Uses in Chemistry:

Isotopes are used in various branches of chemistry like;

1. Analysis of inorganic unknown compounds.
2. Separating a complicated mixture of various components.
3. The trace amount of a metal is determined in a compound.
4. The molecular structure, chemical kinetics, use of catalyst and diffusion of gases is determined with the help of radioisotopes.

2. Uses in medicine:

1. Radioisotopes are commonly used for the diagnoses and treatment of various diseases like cardiac troubles and cancer.
2. The vitamin deficiency and metabolism of the human body is studied with the help of radioisotopes.
3. Surgical instruments, syringes and bandages etc are sterilised with the help of γ -rays.
4. An isotope of cobalt (Co^{60}) is used to kill cancer cells.
5. The cloths of workers of nuclear reactors are made with tracer isotopes to check the side effects of radioactivity.

3. Uses in Agriculture:

1. Genetic changes in plants are studied with the help of radioisotopes.
2. Radioisotopes help to preserve food and vegetables for a long time.
3. Radioisotopes can estimate the rate of absorption of water and food by plants.
4. The process of photosynthesis has been elaborated with the help of radioisotopes.

4. Uses in Industry:

1. Radioisotopes are used in determining the structure of the polymers.
2. The rate of wear and tear of automobile engine parts is determined with the help of radioisotopes.
3. These help to determine the cracks in the under ground pipes.
4. These also help to determine the thickness of metal sheets, paper and cloth.

5. Use in Back Dating:

The age of certain objects can be calculated by means of radioisotope tracers. The age of a dead body or fossil can be determined by C^{14} activity

having a half-life of 5568 years. Libby, an archaeologist in 1960 to around 2600 BC, has calculated the approximate age of Egyptian Pyramids. He was awarded with Nobel Prize for his work.

OBJECTIVE QUESTIONS

Q. Give answer to the following short questions:

1. Define nuclear chemistry.
 2. Define artificial radioactivity.
 3. Define radioactive elements and give two examples.
 4. Describe radioactive rays?
 5. Which elements are stable naturally?
 6. Which elements are unstable naturally?
 7. Write down the names of types of radioactive rays.
 8. Give four properties of Beta rays.
 9. Give two properties each of alpha and gamma rays.
 10. Describe Half Life.
 11. Give any one Nuclear Reaction.
 12. Give four uses of radioisotopes.

Q. Select the correct answer from the following MCQ's.

3. The radioactive elements are

- (a) stable
- (b) unstable
- (c) radioactivity
- (d) half life

4. The constructive use of nuclear energy is

- (a) treatment of various diseases
- (b) nitrogen bomb
- (c) hydrogen bombs
- (d) atomic bomb

5. Alpha rays carry a charge

- (a) positive
- (b) negative
- (c) neutral
- (d) zero

6. Beta rays are actually fast moving

- (a) Nucleus
- (b) electron
- (c) proton
- (d) neutron

7. Rays have no charge and mass as well

- (a) alpha
- (b) beta
- (c) gamma
- (d) no one

8. Rays are more powerful than x-rays

- (a) alpha
- (b) beta
- (c) gamma
- (d) no one

**9. The disintegration of radioactive elements into their half quantity
is called**

- (a) new life
- (b) half life
- (c) old life
- (d) life less

10. Fission means

- (a) to break
- (b) to add
- (c) to waste
- (d) to acquire

11. Fusion means

- (a) to break
- (b) to add
- (c) to waste
- (d) to acquire

- 12.** One atom of uranium-235 emits neutron on breaking
(a) 1 (b) 2
(c) 3 (d) 4

13. The transformation of one element into another is only possible in reactions
(a) Nuclear (b) Fusion
(c) fission (d) neutral

14. Half Life of Radium in years is
(a) 1390 (b) 1490
(c) 1590 (d) 1690

15. The isotope of cobalt is helpful to kill the cancerous cell
(a) Co⁵⁹ (b) Co⁶⁰
(c) Co⁶¹ (d) Co⁶²

16. The genetic changes in plants and animals are studied with the help of
(a) radioactive isotopes (b) hydrogen
(c) alpha rays (d) beta rays

17. The structure and nature of polymers can be determined with the help of
(a) radioactive isotopes (b) nitrogen
(c) alpha rays (d) beta rays

18. The half life of C¹⁴ is years
(a) 5577 (b) 5569
(c) 5567 (d) 5568

19. An archaeologist, determined the age of Egyptian pyramids
(a) Einstein (b) Goldsmith
(c) Curie (d) Libby

20. The age of a dead body or fossil can be determined by
(a) ${}_{6}C^{12}$ (b) ${}_{6}C^{13}$
(c) ${}_{6}C^{14}$ (d) ${}_{6}C^{15}$

LONG QUESTIONS

1. Define nuclear chemistry and radioactivity.
2. Differentiate between alpha, beta and gamma rays.
3. Explain half life process.
4. Give at least six nuclei reactions resulting in the transformation of elements.
5. State important uses of isotopes.



Chapter 10

Alloys

Course contents **2 Hrs**

- 10.1 Introduction with Need
- 10.2 Preparation and Properties
- 10.3 Some Important alloys and their composition

Learning outcomes

After learning this chapter the students would be able to:

- 10.1 Define alloy
- 10.2 Explain different methods for the preparation of alloys
- 10.3 Explain important properties of alloys
- 10.4 Explain the composition, properties and uses of alloys

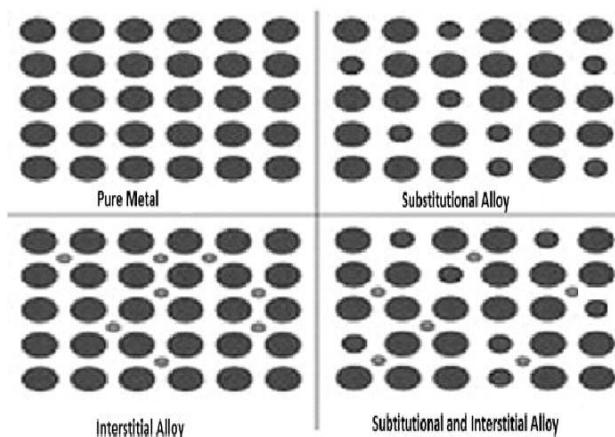
INTRODUCTION

Alloy has very important role in our daily life. Our buildings, utensils in the kitchen, vehicles, computers, mobile phones, chairs, most of the engineering and medical equipments, machineries, and tools are using different types of alloys. This means many alloys have been made and being used by human being.

It is not easy to get a pure metal. But when we get a pure metal, its use in engineering is very rare. Even pure metals are not used for domestic work. For example, if we want to prepare an ornament from pure gold, it is not possible because gold is flexible. So some amount of copper is added to harden it. The pure metals are very soft, highly chemically reactive, and they have low resistance to corrosion and cannot be used for engineering purposes.

The iron is used in the form of steel which is an alloy of iron with carbon, nickel, manganese, etc. Iron shows the desired properties such as hardness, toughness, corrosion resistance, etc. When a metal and other substances are mixed in their molten state, it solidify and form a mixture called an alloy. Some alloys have non-metals like carbon, boron, sulphur, phosphorous, etc. Alloys are used, where their properties are superior to those of the pure metals. Examples of alloys are steel, solder, brass, pewter, bronze and an amalgam. The branch of science which deals with the study of alloys is called Physical Metallurgy. The alloy components are usually measured by mass. Alloys are classified as ferrous or non ferrous alloys. They can also be classified as substitutional alloys, interstitial alloys and substitutional & interstitial alloys depending on the atomic arrangement that forms the alloy.

As shown in the figure given below



Need of Alloys

Pure metals do not have the required properties. So the properties of metals can be improved by alloying them with some other metals or nonmetals, according to the need. We need alloys because they provide the following advantages as compared to pure metals. Alloys are made to:

- Increase the hardness of a metal.

- Lower the melting point.
- Increase tensile strength.
- Increase corrosion resistance.
- Modify colour.
- Provide better castability.
- Increase electrical resistance.
- Increase machinability of metal.
- Improve malleability and ductility of metal.

DEFINITION

A mixture of a metal with other substances (metal or non metal) to have superior properties is called an alloy. These superior properties are strength, hardness, durability, ductility, tensile strength and toughness etc. The base metal is the majority of the alloy. For example, mild steel is 0.1 - 0.3% Carbon and 99.9 - 99.7% Iron.

PREPARATION OF ALLOYS

There are four commonly used methods for the manufacture of alloys: the fusion method, the electro-deposition method, the reduction method, and powder metallurgy.

1. Fusion Method

This method uses alloying elements in a fixed proportion and fuses them together in a refractory melting pot or in a brick-lined crucible. The component metal with a higher melting point is melted first and then the other component with a lower melting point is added to the melt. Both metal components are mixed well and allowed to melt further. The molten mass is covered by powdered Carbon to avoid oxidation of the molten alloy components because they are very reactive to the surrounding atmospheric oxygen. The resulting molten mass is allowed to cool at room temperature.

2. Electro-Deposition Method

Different component metals can be deposited from a solution of their salts by a process known as electrolysis, or electro-deposition. The process involves passing electricity through the solution, or electrolyte, so that charged metal atoms (ions) are attracted to and deposited on the electrode of opposite charge.

3. Reduction Method

Many metals exist naturally as compounds or ores. Reduction method involves the reduction of a suitable compound of one component of alloy in the presence of other component metal in an electric furnace. For example, aluminium bronze is prepared by reducing aluminium oxide in the presence of copper.

In the above three methods used to prepare alloys, Carbon, salts, and oxides are formed that may hinder the properties of the produced alloy.

4. Powder Metallurgy

Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shape or form (compacting), and then heating the compressed material in a controlled atmosphere to bond the material (sintering). The powder metallurgy process generally consists of four basic steps: powder manufacture, powder blending, compacting, and sintering. Compacting is generally performed at room temperature, and the elevated-temperature process of sintering is usually conducted at atmospheric pressure. Optional secondary processing often follows to obtain special properties or enhanced precision. Advantages of Powder Metallurgy over other methods are given below.

1. No secondary operations are required in Powder metallurgy.
2. No further machining is required.
3. It has high Production Rate.

4. It has low Unit Cost.
5. It can produce complicated forms with a uniform microstructure.
6. Powder metallurgy can produce a variety of alloying systems.
7. It can produce parts with specific physical and mechanical properties like hardness, strength, density and porosity.
8. By using powder metallurgy, parts can be produced with special characteristics.
9. It can be used to produce bi-metallic products, porous bearing and sintered carbide.
10. In Powder metallurgy no material is wasted.

PROPERTIES OF ALLOYS

1. Visual attractiveness

Alloys are more attractive and beautiful as compared to the metals. For example, German Silver, Stainless Steel and Bronze etc.

2. Hardness

Alloys are hard as we know carbon steel is ten times more hard than iron.

3. Chemical Reactivity

Alloys are less reactive than metals. For example Stainless Steel does not react with dilute acid on the other hand iron reacts with it.

4. Colour

Alloys are more colourful than metals. For example Bronze, Stainless steel and coin metals etc.

5. Strength

Alloys have good strength than pure metals. For example, German Silver and Steel.

6. Resistance to Corrosion

Alloys show more resistance against corrosion as compared to pure metals. For example Stainless Steel, German Silver, Brass and Duraluminium etc.

7. Electrical Conductivity

Usually alloys are poor conductor of electricity as compared to pure metals. That is why alloys are not used for conduction of electricity. However alloys are used to manufacture heating elements. Heating elements offer resistance to electricity produce heat.

8. Melting Point

One property that almost all alloys have is that their melting point is lower than the pure form of their base metal. For example, Stainless Steel has a melting point that is lower than pure iron, and Brass has a melting point lower than pure copper.

SOME IMPORTANT ALLOYS

<i>Name of Alloy</i>	<i>Composition</i>	<i>Properties</i>	<i>Uses</i>
Brass	Cu = 67% Zn = 33%	Harder than Cu, ductile , work hardens quickly	Marine fittings, condenser tubes, cartridge cases and other house hold articles.
Bronze	Cu = 90% Sn = 10%	Soft, ductile and durable	Pumps, wires, flangs, utensils, coins, Starters
German Silver	Cu = 60% Zn = 25% Ni = 15%	Good strength, high resistance of corrosion in salt water, extremely	Utensils, cutlery, screws, decorative articles.

		ductile and malleable	
Nichrome	Ni = 62% Fe = 23% Cr = 15%	Non-magnetic , high resistance to electric current and heat up It does oxidize up to 1000°C.	It is used as high temperature heating element in electric heaters, Irons etc.
Stainless Steel	Fe = 62-72% Ni = 07-08% Cr = 18-30% C = 0.6-0.7%	Shiny, strong and durable. It has high resistance of corrosion	Surgical instruments and number of things of daily use. Used in wire and ribbon forms in industries.
Solder	Pb = 67% Sn = 33%	Low Melting point	Sealing canes, soldering electrical connections
Duralumin	Al = 95% Cu = 4% Mn = 5% Mg = 5%	Light, tough, nearly as strong as steel but 1/3 of its density, highly ductile, corrosion resistant and has good machinability	Air craft in dustrg auto mobile parts, Surgical instruments, cables, tube light caps, etc.

Amalgams			
1- Silver Amalgam	Hg=50% Ag=30% Sn=13% Cu=6% and other trace elements	Silver amalgam is semi solid and paste like but after sometime become solid.	Silver amalgam is used to fill dental cavities.
2- Sodium Amalgam	Hg Na	Amalgams with 2% Na are solids at room temperature, whereas some more dilute amalgams remain liquid.	Sodium amalgam is used as reducing agent in chemical reactions.

OBJECTIVE QUESTIONS

Q. Give short answers to the following questions:

1. Define Alloys and give two examples.
2. Name four methods for the preparation of Alloys.
3. Describe preparation of Alloys by Fusion Method.
4. Describe preparation of Alloys by Reduction Method.
5. Describe preparation of Alloys by Electro-deposition Method.
6. Describe preparation of Alloys by Powder Metallurgy Method.
7. Give the composition of Stainless Steel.
8. Give the composition of German silver.

9. Give the composition of Nichrome.
 10. Give the composition of Brass.
 11. Give the composition of Bronze.
 12. Give two properties of Alloys.

Q. Encircle the correct answer from the following MCQ's.

8. Which method of alloy preparation is preferable over others

- | | |
|---------------|------------------------|
| (a) Fusion | (b) Electro-deposition |
| (c) Reduction | (d) powder metallurgy |

9. The most important property of Stainless Steel is it's

- | | |
|------------------|----------------------------------|
| (a) colour | (b) density |
| (c) Low strength | (d) high resistance of corrosion |

10. Brass is an alloy of copper and

- | | |
|--------|--------|
| (a) Zn | (b) Sn |
| (c) Ni | (d) Mn |

11. In German Silver copper % age is

- | | |
|--------|--------|
| (a) 60 | (b) 70 |
| (c) 80 | (d) 90 |

12. In Bronze copper % age is

- | | |
|--------|--------|
| (a) 60 | (b) 70 |
| (c) 80 | (d) 90 |

13. Nichrome is an alloy of nickel, chromium and

- | | |
|--------|--------|
| (a) Zn | (b) Sn |
| (c) Fe | (d) Mn |

14. Solder is an alloy of lead and

- | | |
|--------|--------|
| (a) Zn | (b) Sn |
| (c) Fe | (d) Mn |

15. Which alloy is used in heating elements

- | | |
|-------------------|------------------|
| (a) Brass | (b) Nichrome |
| (c) German Silver | (d) Duraluminium |

16. Which alloy is used to fill dental cavities

- | | |
|--------------------|------------------|
| (a) Brass | (b) Nichrome |
| (c) Silver Amalgam | (d) Duraluminium |

17. Which alloy has iron

18. Which alloy has lead

19. Which alloy has mercury

20. The most important component of Alloy is

LONG QUESTIONS

1. Describe Four Methods for the preparation of Alloys.
 2. Describe important properties of Alloys.
 3. Enlist Four important Alloys with their composition, properties and uses.
 4. Describe the needs of Alloys.
 5. Describe advantages of powder metallurgy method over methods of Alloys formation



Chapter 11

Corrosion

Course Contents **2 Hrs**

- 11.1 Introduction with causes
- 11.2 Types of Corrosion
- 11.3 Rusting of iron
- 11.4 Protective measures against corrosion

Learning outcomes

After learning this chapter the student would be able to:

- 11.1 Define Corrosion
- 11.2 Describe different types of corrosion
- 11.3 State the causes of corrosion
- 11.4 Explain the process of rusting of iron
- 11.5 Describe methods to prevent/control corrosion

CORROSION – INTRODUCTION:

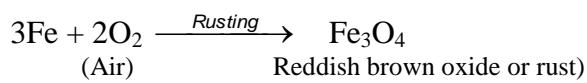
Corrosion, for engineers, is a serious problem because the life of the Industrial equipment / plant is very much reduced due to corrosion. The loss due to corrosion varies from country to country, from industry to industry and from process to process. In Pakistan, due to its tropical climate, the corrosion problem is more serious than in cold countries. Corrosion is a ‘billion dollar thief.’ According to a recent assessment the loss due to corrosion in USA is more than 350 billion dollar per year. Right from a pin to huge structures like

ships, bridges etc are spoiled by corrosion. Roughly about $\frac{1}{4}$ th of the world production is wasted by it.

The rusting of iron things, a black deposit on silver ornaments or a greenish layer on the surface of copper utensils is a common observation and all this is corrosion. The iron things on the sea-side are comparatively quick rusted as compared with the articles used in the interior of a country. This is due to larger amount of moisture in air on the sea-side. With the exception of gold and platinum etc. all the metals are changed to their oxides. Corrosion of materials other than metals is commonly called degradation.

Definition of Corrosion

The gradual destruction of metals by chemical reaction with the atmosphere is called corrosion. This is because of metal oxidation. Metals have a tendency to return to their natural state, it is a chemical reaction which produces salt or oxide. It requires four elements i.e. anode, cathode, an electrolyte, and a metallic path (metal to metal contact). An example of corrosion is the rusting of Iron.



Causes of Corrosion

Some of the factors that cause corrosion are given below.

1. **Water**:-Water is the chief trouble maker. When the metal comes in contact with dissolved oxygen in water, it loses electrons or is oxidized to from metal ion, which forms an insoluble metal oxide.
2. **Acids**:-Metals corrode faster in acidic solution, which has higher concentration of hydrogen ions. For example hydrochloric acid or sulphuric acid would corrode metal much more quickly than moist air alone.

3. **Salts**:-Dissolved salts are ionized. For example sodium chloride is dissociated into sodium and chloride ions. These ions act as charge carriers and increase the conductivity of water. Since corrosion is an electro-chemical process, increased conductivity increases the rate at which the metal is oxidized and corrosion accelerates. That is why exposed metal corrode faster in the salty air of cities near to the sea.
4. **Oxygen**: Oxygen is the most important culprit of all, the element that actually reacts with the metal to form an oxide. Without dissolved oxygen in water, corrosion will not take place.
5. **Oxidation potential of Metal**:-The intensity of the corrosion depends on the position of the metal in the Electrochemical Series .The higher is the oxidation potential, the more will be corrosion of the metal.
6. **Pores in Oxide layer**:-Oxidation potential of aluminum is more than iron but iron corrodes more as compared to aluminum. The aluminum oxide layer is non porous and iron oxide layer has many pores.
7. **Stress**:-Manufacturing processes such as machining, forming, welding, or heat treatment can leave stresses in metal articles. This stress can cause corrosion.
8. **Improper Selection of Metal**:-Metals have a wide range of corrosion resistance. The most active metals such as magnesium and aluminum corrode easily. The most noble metals such as gold and platinum do not corrode easily. Improper metal selection can cause corrosion.
9. **Micro-organisms**:-Microbial attack includes actions of bacteria, fungi, or molds. Micro-organisms occur nearly everywhere and grow on waste living matter. The organisms causing the greatest corrosion problems are bacteria and fungi.

10. Temperature:-Corrosion is accelerated by higher temperature environments which accelerate chemical reactions and allow greater moisture content at saturation in air.

TYPES OF CORROSION

There are different types of corrosion which depend on the environment surrounding the material, type of material, chemical reaction etc. Some general types of Corrosion are described below.

1. Uniform Corrosion

This is also called General corrosion. It is a very common method of corrosion. It deteriorates the whole surface of the metal and makes the surface thin. If it is not controlled it can destroy the whole metal.

2. Galvanic Corrosion

When two metals become electrically connected in an electrolyte, the more active metal which has a high oxidation potential becomes the anode after losing electron(s) and it corrodes fast. But the less active metal becomes the cathode after gaining electron(s). So at the joint where the two non similar metals meet, the galvanic corrosion appears. Thus galvanic corrosion can be controlled by selecting the two metals which are close in electrochemical series.

3. Chemical Corrosion or Dry Corrosion

Corrosion on the surface of a metal is due to direct reaction of atmospheric gases like oxygen, halogens, oxides of sulphur, oxides of nitrogen, hydrogen sulphide and fumes of chemicals with metal in the absence of water. The extent of corrosion of a particular metal depends on the chemical affinity of the metal towards reactive gas.

Oxygen is mainly responsible for the corrosion as compared to other gases and chemicals.

4. Pitting Corrosion

This occurs because of random attacks on particular parts of the metal's surface. This makes holes which are large in depth. These holes are called "pits". The pit acts as the anode while the undamaged part of the metal is the cathode. For example, it can be very harmful in gas lines.

5. Stress Corrosion Cracking (SCC)

It is a complex form of corrosion which arises due to stress and corrosive environment. The main reasons for stress corrosion are welding, heat treatments, deformation etc.

6. Corrosion Fatigue

Corrosion fatigue is produced when a metal breaks at a stress level which is lower than its tensile strength. It is strongly affected by the environment in which the metal lives. It can be produced by the influence of various types of stress like stress applied, thermal expansion, thermal contraction, welding, soldering, cleaning, heat treatment, construction process, casting etc.

7. Soil Corrosion

Underground pipes, cables etc corrode due to soil corrosion. It is caused due to moisture, pH of soil and micro-organisms. Soil has different quantities of air at different places. This is also a cause of soil corrosion.

8. Erosion Corrosion

It is also called flow-assisted corrosion. This is due to the movement of corrosive liquids on metal surface which damages the material. It can be seen in ship propellers which are constantly exposed to sea water.

RUSTING OF IRON

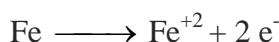
The corrosion process is very complex and is still not fully understood today. There are many theories about rusting of iron but the following two theories are most important i.e. Electrochemical Theory and Acid Theory.

Electrochemical Theory of Rusting of Iron

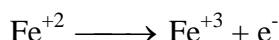
It is a very complex process which is completed in the following steps.

Oxidation of iron

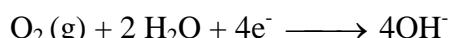
- First the iron gets oxidized into ferrous ions [Fe (II)] with the loss of electrons.



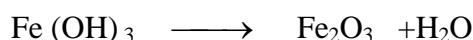
- The ferrous ions again get oxidized into ferric ions [Fe (III)] in the presence of water and oxygen.



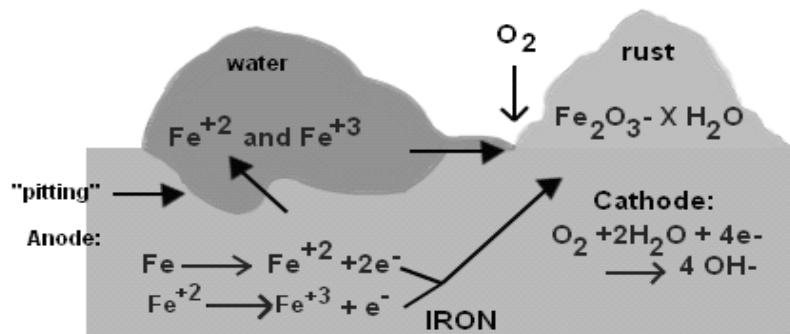
- These electrons from the above reactions are used to reduce oxygen.



- The ferric ions combine with oxygen and form ferric oxide [iron (III) oxide]. This ferric oxide gets hydrated with water.



The complete chemical reaction for rust formation is shown below. The mechanism for the rusting process is similar to the electrochemical cell. The electrons formed during the oxidation of iron are conducted through the metal. Thus, the iron ions diffuse from the water layer to the metal surface where oxygen is present.



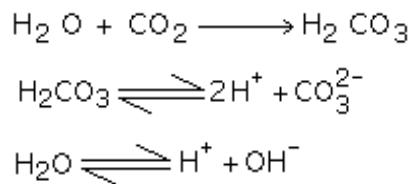
This is an electrochemical cell where iron acts as the anode and oxygen gas as the cathode. The aqueous solution of ions behaves like a "salt bridge" as shown in the figure.

Rusting happens faster in the presence of moisture rather than in a dry environment. This process is also affected by some other factors like the presence of other salts, which increases the rate of rusting, because the presence of salt enhances the conductivity of the aqueous solution formed at the surface of the metal. So the rusting of iron and steel is completed rapidly near the sea (salty) or with salt.

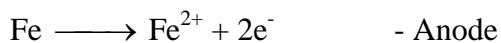
Acid Theory of Rusting of Iron

According to this theory water and carbon dioxide react to produce carbonic acid which reacts with iron to produce rust. The following are the steps of rusting of iron.

1. Water on the metal surface dissolves CO₂ and O₂ from the air.



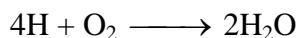
2. Fe in contact with dissolved CO₂ (carbonic acid) and O₂ undergoes oxidation.



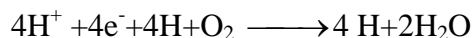
3. Electrons lost by Fe are taken by H⁺



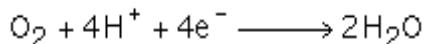
4. On multiplying the above equation by 4



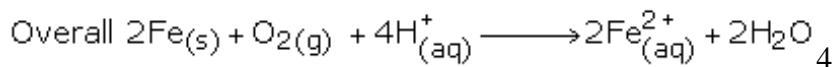
5. By adding above two equations



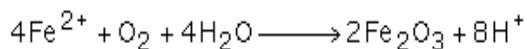
6. Now subtracting 4H both sides of the equation



7. The dissolved O₂ can take electrons directly also.



8. Fe²⁺ reacts with dissolved O₂ and water



Rust (Hydrated ferric oxide)

Methods of Corrosion prevention/Control

Five main techniques are used for limiting corrosion rates to practical levels:

1. Metal Selection
 2. Coatings
 3. Cathodic Protection
 4. Alloy Formation
 5. Chemical Corrosion Inhibitors
1. Metal selection is picking a metal that is resistant to the particular corrosive environment and also meets other requirements such as cost and mechanical properties of the metal.
 2. Coatings are the most widely used method for controlling corrosion. To protect a metal surface from corrosion, the contact between the metal and the corrosive environment is to be cut off. This is done by coating the surface of the metal with a continuous, non-porous material, insert to the

corrosive atmosphere. Such a coating is referred to as surface coating or protective coating. In addition to protective action, such coatings also give a decorative effect and reduce wear and tear.

The different methods used for metal coating are.

(i) **Hot dipping-** In the process of hot dipping, the metal to be coated is dipped in the molten bath of the coating metal. Such hot dip coatings are generally non-uniform.

(a) **Galvanization** - The process of coating a layer of zinc on iron is called galvanization. The iron article is first washed with dilute sulphuric acid to remove traces of rust, dust, etc. at 60-90 °C for about 15 -20 minutes. Then this metal is dipped in a molten zinc bath maintained at 430 °C. The coated base metal is then passed through rollers to correct the thickness of the film. It is used to protect roofing sheets, wires, pipes, tanks, nails, screws, etc.

(b) **Tinning**-The coating of tin on iron is called tin plating or tinning. In tinning, the base metal is first washed with dilute sulphuric acid to remove surface impurities. Then it is passed through molten tin covered with zinc chloride flux. The tin coated article is passed through a series of rollers immersed in a palm oil bath to remove the excess tin. Tin coated utensils are used for storing foodstuffs, pickles, oils, etc

(ii) **Metal spraying**-Metal spraying is spraying hot metal on a surface of another metal to create a coating.

(iii) **Cladding**- Cladding is the bonding together of dissimilar metals. It is achieved by pressing or rolling sheets together under high pressure.

(iv) **Cementation**- Cementation coatings are surface alloys formed by diffusion of coating metal in to the base metal, producing little dimensional change.

- (a) **Sherardizing** – Cementation with Zinc powder is called Sherardizing.
- (b) **Chromizing** - Cementation with 55% Chromium powder & 45% Alumina is called chromizing
- (c) **Calorizing** – Cementation with Aluminium and Alumina powder is called Calorizing

(v) Electroplating or electro-deposition.

Electroplating is process in which the coat metal is deposited on the base metal by passing a direct current through an electrolytic solution.

(vi) **Paints**-The different types of paints are applied to protect metals.

(vii) Oil and greasing--Different oils and greases are also used to prevent metals from corrosion.

3. **Cathodic protection** In the process of corrosion there is a flow of DC current (Electrons) from the surface being attacked. Cathodic protection (often known as CP) provides a flow of DC current in opposite direction to nullify the corrosion current. Usually the impressed current is obtained from an external DC source. The rate of corrosion is greatly reduced to protect metal for 10 to 20 years or more. Thus CP is used with some type of coating. No coating is 100% free of small bare spots. Using CP with a coating means current is only needed at these bare spots. Sui gas pipe lines are being protected by this method in Pakistan.
4. Alloys Formation is also used to protect metals from corrosion. For example in Stainless Steel chromium produces a sound chromium oxide layer which protects the steel from corrosion.
5. Chemical Corrosion Inhibitors are solid, liquid or gas compounds. They are added in small quantities to the given corrosive environment to change its interaction with the metal to be protected.

OBJECTIVE QUESTIONS

Q. Give short answers to the following questions:

1. Define Corrosion and give its one example.
 2. Name any four types of corrosion.
 3. Why exposed metal corrode faster in the salty air of cities near to the sea? Name any four factors that cause corrosion.
 4. Describe Galvanic Corrosion.
 5. Describe Chemical or Dry Corrosion.
 6. Describe Pitting Corrosion.
 7. Describe Electroplating.
 8. Describe chlorizing.
 9. Describe metal spraying.
 10. Describe Tinning.
 11. Describe Galvanization.

Q. Encircle the correct answer from the following MCQ's.

1. In corrosion the chemical reaction is

2. Which one of the following causes corrosion of Iron

3. The colour of corrosion product of silver is

4. The colour of corrosion product of copper is

5. Which one of the following metal does not corrode
(a) zinc (b) platinum
(c) sodium (d) magnesium

6. The chemical composition of rust is
(a) $\text{FeO} \cdot \text{H}_2\text{O}$ (b) Fe(OH)_3
(c) $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$ (d) Fe(OH)_2

7. Machining, forming, welding, or heat treatment of metal can cause
(a) stress corrosion (b) uniform corrosion
(c) pitting corrosion (d) dry corrosion

8. A common corrosion which deteriorates the whole surface of the metal and makes the surface thin is
(a) stress corrosion (b) uniform corrosion
(c) pitting corrosion (d) dry corrosion

9. The corrosion due to the movement of corrosive liquids is
(a) stress corrosion (b) erosion corrosion
(c) pitting corrosion (d) soil corrosion

10. The corrosion of underground pipes, cables etc. is called
(a) stress corrosion (b) erosion corrosion
(c) pitting corrosion (d) soil corrosion

11. The corrosion of iron is called
(a) rust (b) erosion corrosion
(c) galvanic corrosion (d) soil corrosion

12. The corrosion makes holes which are large in depth is called
(a) pitting corrosion (b) erosion corrosion
(c) crevice corrosion (d) soil corrosion

- | | |
|-------------------|----------------|
| (a) calorizing | (b) cladding |
| (c) galvanization | (d) chromizing |

LONG QUESTIONS

1. State the causes of corrosion.
2. Describe different types of corrosion.
3. Explain the process of rusting of iron.
4. Describe different methods to prevent corrosion.



Chapter 12

Electrochemistry

Course contents**2 Hrs**

- 12.1 Ionisation and Arrhenius theory of ionisation
- 12.2 Electrolytes and Electrolysis
- 12.3 Faraday's laws and numericals related to them
- 12.4 Applications of electrolysis
- 12.5 Electro chemical cells

Learning outcomes:

After learning this chapter the students would be able to

- 12.1 Define ionisation, electrolyte and electrolysis
- 12.2 Describe Arrhenius theory of ionisation
- 12.3 State Faradays laws of Electrolysis
- 12.4 Apply Faraday's laws in different field of industry
- 12.5 Solve numericals problem on Faradays laws
- 12.6 Explain the construction and working of Daniel cell and Lead accumulator

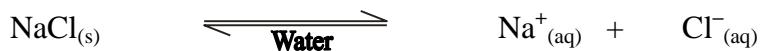
Introduction to Electrochemistry:

The branch of chemistry, which deals with the relationship between chemical changes and electricity, is called '*Electro-chemistry*'. Or the branch of chemistry that is concerned with the electrolysis and other similar phenomenon occurring when a current is passed through a solution of an

electrolyte, or concerned with the behaviour of ions in solution and the properties shown by these solutions, is called '*Electro-chemistry*'. Or it is that branch of chemistry, which deals with the conversion of electrical energy into chemical energy and vice versa in the galvanic or voltaic cell is, called '*Electro-chemistry*'.

Ionisation:

The process in which an electrolyte when dissolved in water or is melted, undergoes dissociation into two charged fragments is called ionisation. For example when NaCl is dissolved in water, it dissociates as;

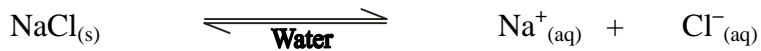


Arrhenius theory of ionisation:

A Swedish scientist, Arrhenius in 1884 put forward his theory of electrolytic dissociation or ionisation in order to explain the conductivity of electrolytes, electrolysis and certain other properties of electrolytic solutions.

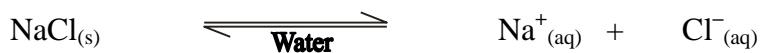
Postulates:

- When an electrolyte (acid, base or salt) is dissolved in water, it dissociates into positive and negative ions. The positive ions are called '*cations*' and the negative ions are called '*anions*'. These ions can move freely in solution in any direction.



- The properties of an electrolyte in solution are the properties of the ions produced in the solution. Each ion has its own specific physical and chemical properties.

- The electrolytes splits into ions and the ions so formed in solution constantly recombine with each other to form the neutral unionised electrolyte. Thus, there is a state of dynamic equilibrium between the ions and unionised electrolyte. Ionisation is thus a reversible process.



According to law of mass action

$$K_c = \frac{[\text{Na}^+][\text{Cl}^-]}{[\text{NaCl}]}$$

Where K_c is the ionisation constant.

4. When an electric current is passed through the solution of an electrolyte, the +ive ions move towards the cathode and the -ive ions move towards the anode. This movement of ions is responsible for the conduct of electricity in the solution of an electrolyte. These ions migrate towards the oppositely charged electrodes.
5. The whole of the electrolyte dissolved in water does not undergo complete dissociation. It is attained only at infinite dilution. It depends on;
 - i. **The nature of the electrolyte:** Strong electrolytes dissociate completely as compared to weak electrolytes, which dissociate to lesser extent.
 - ii. **The dilution of the solution:** The more dilute the solution is, the greater will be the degree of dissociation of an electrolyte.
 - iii. **The temperature:** The higher the temperature, the greater will be the degree of dissociation of an electrolyte.
6. The electrical conductivity of the solution of an electrolyte depends on the following factors;
 - i. **The number of ions present in the solution:** The greater is the number of ions per unit area in the solution, the greater is the conductivity of the solution.
 - ii. **The speed of the ions present in the solution:** The conductivity of the solution is directly proportional to the speeds of ions present in the solution.

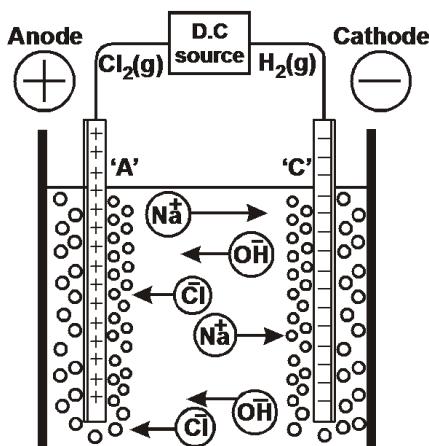
ELCTROLYTES.

The substance which in solution or molten state conduct electricity are known as electrolytes. For example, different acids, bases and salts.

ELECTROLYSIS:

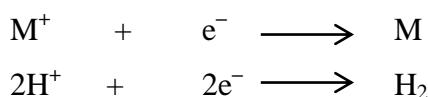
The use of electric current to produce a chemical reaction is called '*electrolysis*'. Or the process in which ions of an electrolyte in aqueous or molten state move towards opposite electrodes under the influence of applied electric current and are either deposited on them or go into solution by acquiring or loosing electrons.

Consider an electrolytic cell containing a solution of electrolyte equipped with two platinum electrodes. These are connected to battery as shown in the diagram. Electrode 'C' is connected to the -ive terminal of the battery by which the electrons enters the solution and is called '*cathode*'. Electrode 'A' is connected to the +ive terminal of the battery by which the electrons leaves the solution and is called '*anode*'. The solution contains ions produced by the dissolved electrolyte. The cations may be metallic ions M^+ or H^+ , where as the -ive ions may consists of halogen ions X^- or OH^- . These ions move with the influence of electric current applied.



Electrolysis

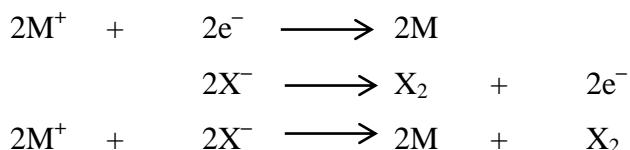
At *cathode*: Reduction process takes place as follows;



At *anode*: Oxidation process takes place as follows;



The above reactions are called half reactions. The over all reaction is



This sort of motion of ions and cations towards the respective electrodes with all the accompanying chemical changes in an electrolytic solution under the influence of an applied electric current is known as '*electrolytic conduction or electrolysis*'.

It is also evident from the process of electrolysis that the transfer of electrons takes place by the migrations of ions resulting in the transport of matter from one part of the electrolytic conductor/ electrode to another. For example in the solution of NaCl,

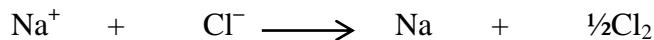
At cathode;



At anode;



The over all reaction is:



FARADAY'S LAW OF ELECTROLYSIS:

Michael Faraday in 1930 studied the inter-relationship between the extent of chemical changes taking place and the quantity of electricity passed through a solution and calculated the amount of the electrolytes deposited on the electrode or the quantity of electrolyte going into solution. On the basis of his experiments he deduced the following two laws of electrolysis.

Faraday's 1st law:

It states that the amount of any substance deposited or liberated at an electrode is directly proportional to the quantity of electricity passed through the solution. Or the amount of a chemical substance produced or liberated (W) is directly proportional to the quantity of electricity (Q) passed through the cell. Mathematically

$$W \propto Q$$

$$W = ZQ$$

Where W = mass of the substance liberated or deposited, Q = quantity of electricity passed in Coulomb & Z = electro-chemical equivalent.

As Q = Coulomb = I x t (ampere x time), so

$$W = ZIt$$

Faraday's 2nd law:

It states that the amount of different substances deposited or dissolved during electrolysis by the same quantity of electricity are directly proportional

to their equivalent weights. Or if the same quantity of electricity is passed through different electrolytes, the amount of different substances (W) deposited or dissolved are directly proportional to their chemical equivalent masses (Z). Here the quantity of electricity passed is called “*Faraday*”. It is equal to 96500C (C= columb). Mathematically

$$W \propto Z$$

& $Z \propto F$ (Z = equivalent mass)

So by putting these values in the 1st law, we get

$$W = \frac{ZIt}{F}$$

Or $W = \frac{ZIt}{96500}$ (as 1F = 96500C)

It can also be written as;

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

Numerical problems on Faraday's law:

1. Calculate the Electro-chemical equivalent of silver when a current of 2 Ampere is passed through its solution for 15 minutes and the amount of silver obtained is 2.0124g.

$$\begin{aligned}
 W &= 2.0124\text{g} \\
 Z_{\text{Ag}} &=? \\
 t &= 15 \text{ min} = 15 \times 60 \text{ sec} \\
 I &= 2 \text{ A} \\
 W &= ZIt \quad \text{or} \\
 Z &= \frac{W}{It} \\
 &= 2.0124 / 15 \times 60 \times 2 = 0.001118 \text{ Ans.}
 \end{aligned}$$

2. Calculate the amount of potassium liberated by passing a current of 10A for 10 min. through molten KCl solution.

$$\begin{aligned}
 W &= ? \\
 I &= 10\text{A} \\
 t &= 10 \text{ min} = 10 \times 60 \text{ sec} \\
 Z_K &= \text{Equivalent mass} = 39 \\
 F &= 96500\text{C} \\
 W &= \frac{ZIT}{F} \\
 W &= \frac{39 \times 10 \times 60 \times 10}{96500} \\
 &= 2.4248\text{g of potassium.}
 \end{aligned}$$

3. Determine the amount of sodium liberated by passing a current of 50A for 1 hour through its NaCl molten solution.

$$\begin{aligned}
 W &= ? \\
 I &= 50\text{A} \\
 t &= 1\text{h} = 1 \times 60 \times 60 \text{ sec} \\
 Z_{\text{Na}} &= \text{Equivalent mass} = 23 \\
 F &= 96500\text{C} \\
 W &= \frac{ZIT}{F} \\
 W &= \frac{23 \times 50 \times 1 \times 60 \times 60}{96500} \\
 &= 42.9\text{g of sodium.}
 \end{aligned}$$

4. Two cells of nickel and copper were arranged in series and a certain quantity of electricity was passed. The amount of Ni obtained was 27.80g. What will be the weight of copper?

$$\text{Weight of Cu} = ?$$

$$\text{Weight of Ni} = 27.80\text{g}$$

$$Z_{\text{Ni}} = 29.5$$

$$Z_{\text{Cu}} = 31.78$$

$$\frac{\text{Weight of Ni}}{\text{Weight of Cu}} = \frac{\text{Equivalent weight of Ni}}{\text{Equivalent weight of Cu}}$$

$$\text{Weight of Cu} = \frac{\text{Equivalent weight of Cu}}{\text{Equivalent weight of Ni}} \times \text{weight of Ni}$$

$$\text{Weight of Cu} = \frac{31.78}{29.50} \times 27.80$$

$$= 29.94\text{g Ans.}$$

5. Calculate the Electro-chemical equivalent of copper when a current of 10 Ampere is passed through a solution CuSO₄ for 15 minutes and the amount of copper obtained is 2.96g.

$$W = 2.96\text{g}$$

$$Z_{\text{Cu}} = ?$$

$$t = 15 \text{ min} = 15 \times 60 \text{ sec}$$

$$I = 10 \text{ A}$$

$$W = ZIt \text{ or}$$

$$Z = \frac{W}{IT}$$

$$= \frac{2.96}{10 \times 15 \times 60}$$

$$= 0.0003288 \text{ Ans.}$$

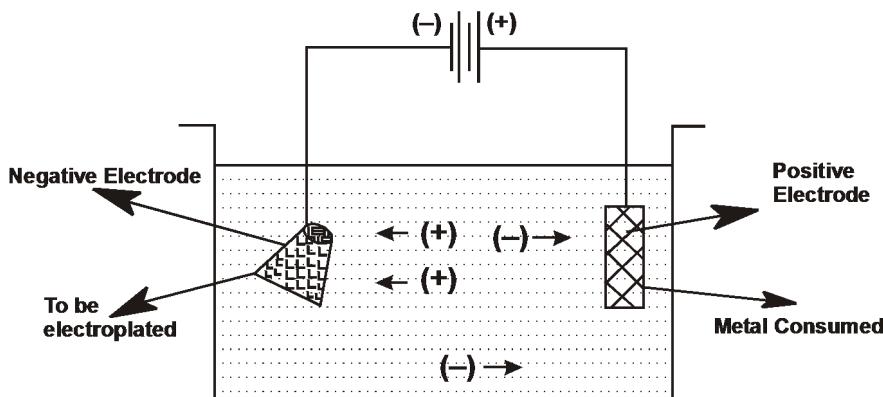
APPLICATIONS OF ELECTROLYSIS:

Following are the major applications of electrolysis;

1. Electroplating:

It is the process of depositing a thin layer of a better, beautiful and costly metal on another inferior and cheaper metal called base metal with the

help of electricity. Generally nickel, silver, gold, zinc, platinum and chromium are electroplated on other articles. The main object of electroplating is to protect the metal from the atmosphere and to make it beautiful.



Electroplating

The metal that is to be used for the coating on the base metal is designated as *anode* in its suitable solution, for example copper anode in copper sulphate solution, nickel in nickel sulphate solution etc, and the article in which coating is to be done is taken as *cathode*.

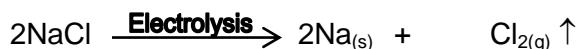
As the DC current is passed through the solution, the ions of the plating metal are coated on the metal object. The plating metal dissolves and produces the ions in the solution to make up its concentration. A thin layer of the coated metal is considered to be more durable.

2. Electro-typing:

It is basically used for the preparation of decoration articles and printing plates. The impression of the design is carved on the wax, and is made conductor by the spray of graphite. This block is made as cathode and Cu as anode dipped in the copper sulphate solution. With the passage of electricity, a beautiful coating of Cu is achieved on the block.

3. Electro-metallurgy:

A number of reactive metals like Na, Ca, K, Mg, & Al etc are extracted by electrolysing their fused solution. For example Na is extracted by the electrolysis of its molten salt, NaCl.



4. Electro-refining:

A large number of metals like Cu, Au, Al, Sn & Ag etc are electrolytically refined to 100% purity. The impure sample of the metal is made as anode while the pure is made as cathode in their respective solutions. With the passage of electricity, a pure metal is obtained.

5. Electrolytic preparation of chemicals:

Many chemicals are prepared by the electrolysis of their respective compounds. For example NaOH, chlorine and hydrogen gas, are prepared by the electrolysis of aqueous NaCl solution. Similarly oxygen and hydrogen are prepared by the electrolysis of water.



6. Determination of equivalent weights:

According to 2nd law of Faraday,

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

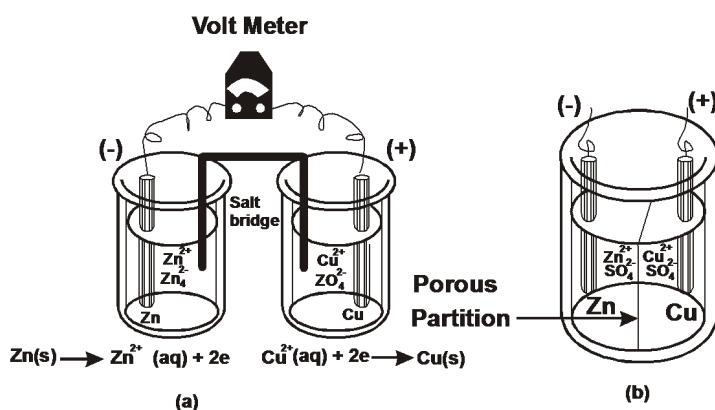
So by knowing the mass of the metal collected on the electrode, their respective equivalent weight can be calculated.

ELECTRO-CHEMICAL CELLS:

Oxidation and reduction (Redox) take place in electrochemical cells. There are two types of Electrochemical cells. They are Galvanic cell and Electrolytic cells. Such cells that produce electric current as a result of chemical reaction are called *Galvanic cells*. Or the cells, in which chemical reaction takes place by electric current are called *Electrolytic cells*.

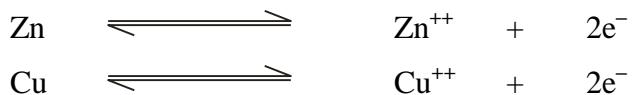
1. Galvanic cell:

The simplest Galvanic cell is also called “*Daniell cell*”. A cell in which a redox reaction produces an electric current is known as Galvanic or Voltaic cell. It consists of a copper and zinc electrodes, which are dipped in their respective solution of CuSO_4 and ZnSO_4 . These are separated by a porous membrane, to permit only ions to pass. In some cells a salt bridge is also used for the same purpose.



Zinc-copper galvanic cell
(a) Cell with salt bridge (b) cell with porous partition

Both Zn and Cu are electro-positive metals and exists in equilibrium as



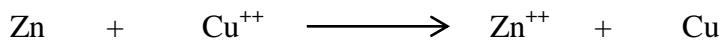
But when both metals are in contact with each other, Zn readily loses electrons as it is more electro-positive than Cu and following oxidation reaction takes place



Cu accepts electrons, as it is less electro-positive than Zn and following reduction reaction takes place



This flow of electrons generates electricity. In the external circuit the current flows from zinc to copper that is copper ions are reduced to metallic Cu while zinc metal oxidises to form zinc ions.



This reaction is spontaneous and continues until the whole reactants are consumed. This reaction produces a current of 1.10V.

2. Lead storage battery or lead accumulator:

Lead storage battery is a useful rechargeable current producing device and it is the lifeline of the automobiles. It consists of a number of electrochemical cells. These are arranged in series i.e. anode of one cell is connected to the cathode of the other cell. The electrodes are made up of spongy lead and lead dioxide, and are dipped in a solution of sulphuric acid of specific gravity 1.125 g/cm³. When the circuit is complete, the Pb plate acts as *anode* and lead dioxide plate acts as *cathode*. The following reaction takes place at cathode;



Following reaction occurs at anode;

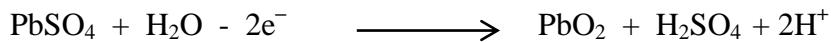


And the overall reaction is:



The battery is discharged with its continuous use as the lead is converted into lead sulphate and water is also produced, which lowers the specific gravity of the acid. So it can be recharged with the passage of current opposite to the previous direction to form lead, lead oxide and sulphuric acid again.

The following reaction takes place at cathode;



Following reaction occurs at anode



And the overall reaction is



It shows that H_2SO_4 is obtained from the deposited PbSO_4 on the electrodes. The generator of the automobiles continuously charges the batteries to keep it in perfect position.

OBJECTIVE QUESTIONS

Q. Write short answers to the following questions.

1. Define Electrolytes with two examples.
2. Define electrolysis.
3. Define electro- chemistry.
4. Describe electrodes.
5. Define oxidation reduction reaction.
6. Define electro-chemical cell.
7. What is the basic difference between Galvanic cell and lead storage battery?
8. State faraday's first law of electrolysis.
9. State faraday's second law of electrolysis.
10. Names factors on which electrical conductivity of solution depends.

11. Describe the term electroplating.
 12. Names four uses of electrolysis.

Q. Encircle the correct answers of the following MCQ's.

LONG QUESTIONS

1. Describe Arrhenius theory of ionisation.
 2. What is electrolysis? Discuss in detail.
 3. Describe Faraday's laws of electrolytes.
 4. What is electroplating. Explain with examples.
 5. What are electro-chemical cells? Briefly describe galvanic cell .
 6. If 15 ampere of current is passed through a solution of NaCl for 45 minutes. Find the amount of sodium collected on cathode. (Ans. 9.65g)
 7. 15 ampere current deposits 10.07g of Ag from silver nitrate solution for 10 minutes. Calculate the electro-chemical equivalent of Ag? (Ans. 0.00111888)
 8. Find the weight of Cu deposited from its solution by a current of 2.5 A flowing for 30 minutes. Z = 31.75 (Ans. 1.48g)

9. Two cells containing solutions of silver nitrate and copper sulphate are connected in series. Calculate the amount of Cu deposited while the mass of silver obtained is 13.25g. (Ans. 3.89g)
10. Two cells containing solutions of silver nitrate and copper sulphate are connected in series. Calculate the equivalent weight of Cu. The mass of Ag & Cu obtained is 4.25g & 1.25g respectively. $Z_{Ag} = 107.9$
(Ans. 31.73)



Chapter 13

Electrical Insulating Materials

Course contents 2 Hrs

- 13.1 Introduction.
- 13.2 Solid insulators with chemical nature.
- 13.3 Liquid insulators with chemical nature.
- 13.4 Gaseous insulators with chemical nature.
- 13.5 Uses and their classification.

Learning outcomes:

After learning this chapter the student would be able to:

- 13.1 Define insulator, conductor.
- 13.2 Classify solid, liquid and gaseous insulators with their chemical nature.
- 13.3 Describe their uses.

INTRODUCTION:

The substances with very low electrical conductivity are called *insulators*. They provide very high resistance to the passage of electric current.

These are used to check the loss of electricity through certain parts of the electrical systems or conductors. Insulating materials have high value of resistivity that is $10^8 - 10^{20}$ ohm-cm. In fact insulators are so important that these help us to handle conductors like live wires safely and soundly. Electrical insulating materials are used in cables, capacitors and transformers. They are widely used for heat and electrical insulation in panel boards and insulating tubes.

Insulators:

The materials, which prohibit or retard the passage of electric current, are called *insulators*. Rubber, plastic, dry wood, glass, mica, asbestos etc are important insulators.

Conductor:

The substances that can allow the passage of electrical current, heat and sound waves through their bulk are known as conductor. For example, all pure metals, acids, bases and salts.

Dielectric:

Insulating materials when used for storing the electric charge are called “dielectric”. For example, plastic and mica etc. The dielectric material is kept between the plates of the capacitor.

Desirable properties of a good insulator:

Following are the major desirable properties of a good insulator;

1. It should have low value of conductivity or high value of resistivity.
2. Its dielectric constant should be low.
3. It should have proper dielectric strength to sustain electric current.
4. It should resist the variations in temperature.
5. It should be non-hygroscopic.
6. It should be non-porous.
7. It should have low co-efficient of thermal expansion.
8. It must be chemically inert.
9. It should have high melting point and boiling point.
10. It should be durable and long lasting.
11. Liquid insulators should be highly viscose.
12. It should be non-inflammable.
13. It should be denser.
14. It should have high break down potential.

Classification of insulating materials:

Insulators are generally classified into three groups on the basis of their physical state.

1. Gaseous insulators
2. Liquid insulators
3. Solid insulators

Gaseous insulators:

The following gases are used as insulators;

a. Common Gases:

1. Air:

It is the most important naturally available insulators and is a gifted dielectric from Almighty Allah to man ensuring safety in electrical transmission with out any cost. However ionisation or oxidation creates some problems. It is used in the overhead transmission of electricity. Its di-electric strength is 5 KV per mm.

2. Hydrogen Gas (H_2):

Hydrogen is the lightest and coolant gas in nature. It increases the efficiency and rate of work of the machines. It is used in turbo-generators & condensers. Its di-electric strength is 2.5 – 4.5 KV per mm.

3. Nitrogen Gas (N_2):

Nitrogen gas is a better insulator than air as it does not take part in the process of oxidation. It is inert gas and is used as insulator in transformers. It is also used in gas pressures cables and electrical capacitors. Its di-electric strength is 3 – 5 KV per mm.

4. Carbon dioxide (CO_2):

It has a better value of dielectric constant (1.000985) and is used as insulator in fixed type capacitors and oil filled high voltage cables and transformers.

5. Inert gases:

Inert gases like argon, neon etc are used in fancy bulbs and tube lights due to their better di-electric strength and thermal conductivity.

b. Electro negative gases:

Some gases are more electronegative and have high value of dielectric constant. These are advantageously used due to their non-explosive and non-inflammable nature. For example Sulphur Hexafluoride (SF_6) and carbon tetra chloride [CCl_4] are generally used. Recently perfluoro propane, Octa fluoro cyclobutane and super fluoro-butane have also been prepared for insulation purposes. Its di-electric strength is 235 times greater than air.

i. Sulphur hexafluoride (SF_6):

SF_6 is a non-toxic and non-flammable gas. It has good coolant properties. It is chemically stable up to $800^\circ C$ and is used in caspacitors, transformer, and cables etc. however it is a corrosive gas.

LIQUID INSULATORS:

Liquid insulators are used as dielectrics and insulators for electricity and heat. Following are the major liquid insulators;

1. Vegetable oils:

These are the oldest insulators used. Drying oils and Non-drying oils like linseed oil, palm oil etc are used in the preparation of insulating varnishes that are used in transformers and motor coils.

2. Mineral oils:

These are the petroleum products. These are stable upto 100°C. Their di-electric strength is 30 – 50 KV per mm. These are used in cables, capacitors and transformers.

3. Organic esters:

These have high value of dielectric constant and are used in high frequency capacitors. For example Amyl Oleate and Tetra hydro furyl oxalate etc.

4. Synthetic hydrocarbon liquids:

These are poly-butylene and polypropylene compounds. These are chemically inert and inflammable. Their properties are like mineral oils and are used in high-pressure gas filled power cables and D.C voltage capacitors.

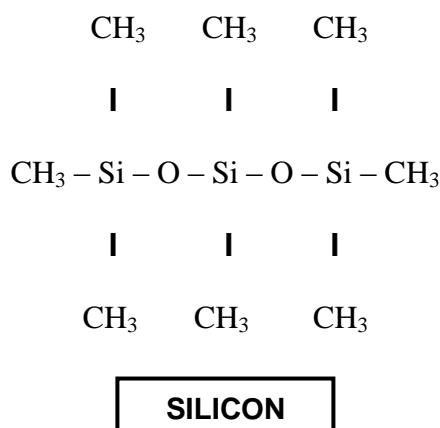
5. Fluorinated Liquids:

These are fluorine substituted organic compounds and have high chemical stability and are non-inflammable. These are extensively used in small sized electric and radio devices and electronic transformers.

6. Silicon Liquids:

These are organic compounds of silicon like dimethyl silicon. These are highly stable at elevated temperature and are non-corrosive to metals. These are widely used as coolants for radar, aircraft and radio transformers.

The structure of silicon is as follows;



7. Askarels:

These are chlorinated hydrocarbons. These are non-flammable and inert. There is no change in their composition with the passage of current. These are quite expensive as compared to mineral oil but their properties like high dielectric constant, electric and heat stability etc make them cheaper. These are used in high voltage transformers. Chlorinated biphenyl, penta-chloro biphenyl, tri-chloro biphenyl, hexa-chloro biphenyl and tri-chloro benzene are some examples of askarels.

SOLID INSULATORS:

Solid insulators are widely used in engineering industry. These are: -

1. Paper and cardboard:

These are prepared from the wood cellulose and cotton. These are quite hygroscopic. So these should be free from moisture. These are used for insulation in winding, cable coils, transformers and different types of capacitors.

2. Fibrous insulators:

These are widely used as insulators due to their mechanical strength, durability, flexible nature, easy processing and of cheaper rates. These also absorb moisture. These are multipurpose and mostly used in winding machines. For example cotton, wool, silk, jute, nylon, fibreglass, asbestos etc.

3. Impregnating coatings and binding materials:

These are high molecular weight organic compounds and are used for insulation purposes. For example

i. **Waxes:** These are basically hydrocarbons. These are soft and flexible.

These may be natural like bee wax or synthetic like cerasine and halo wax etc.

ii. **Varnish:** These are the solution of different types of resins in volatile organic solvents like ether, turpentine oil etc. These become solid after application. These are used in windings of different machines.

iii. **Bonding and adhesive materials:** These are the solutions of phenol resins and are used in low capacity machines. For example insulation tapes.

4. Polymer resins:

These are high molecular weight organic compounds and are used for insulation purposes. These may be natural or synthetic.

i. Natural resins:

These are the vegetable products of natural origin like copal, shellac and amber etc. Copal is used to make the varnish.

ii. Artificial resins:

These are usually prepared by the polymerisation of organic compounds to cope with the shortage of natural resins. These include:

- a) **Polyethylene:** The formula of polyethylene is $-(\text{CH}_2 - \text{CH}_2)_n-$. Its dielectric constant is 2.3. It is used in radio, TV, communication and power cables.
- b) **Polystyrene:** It is hard, rigid and transparent plastic having dielectric constant 2.58 KV per mm. It is used in high frequency capacitors, electrical bushings, telephone and fluorescent light accessories.
- c) **Poly vinyl chloride (PVC):** It is tough, hard and rigid material having dielectric constant 3.0 – 3.3 KV per mm. It is used in electric wires, cables, flexible wire coverings, sleaving and cable sheathing.

- d) **Others:** It includes Teflon, acrylic and cellulose polyesters, phenolic, polyamide and epoxy resins. These are used for insulation purposes.

5. Re-enforced thermoplastics:

These are used to fill circuit breaker, circuit boards and switch parts.

These are also used for the electronic insulation of the coils.

6. Rubber:

Natural rubber is a polymer of isoprene. It is very elastic and its dielectric constant is 2.5 – 5 KV per mm. It is used for the insulation of low voltage wires. Artificial rubbers like butyl rubber, butadiene rubber, chloroprene rubber, and silicon rubber are also available and these are better than natural rubber.

7. Inorganic insulating materials:

Following are important inorganic insulating materials;

- a) **Ceramics:** These include porcelains, alumina ceramics, stearates, and titanates. These are used in telephone and electric poles, fuse cases & holders, switches and wire beads.
- b) **Mica:** It is a crystalline mineral of aluminium and potassium silicate. Its formula is $K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$. It is used as insulator in heating appliances like heater, toaster, iron, and switchgear etc. it can withstand temperature upto 500°C.

- c) **Asbestos:** It is also a natural mineral and is extensively used as insulators in the form of paper, tape, cloth, and board. However it is soft and is vulnerable to crack.
- d) **Glass:** Its dielectric constant is 8.7-10 KV per mm. It is also used as insulator in electric and electronic devices like picture tube, x-ray tube, electron tubes and fluorescent tubes etc.

OBJECTIVE QUESTIONS

Q. Give short answer to the following questions:

1. Describe insulators. Name two gaseous insulators.
2. Give two properties and two uses of askarels.
3. Define dielectric and give two examples.
4. Write four properties of a good insulator.
5. Give uses and properties of SF₆.
6. Name four inorganic and four organic insulating materials.
7. Write insulating properties of silicon liquids. Give their two uses.
8. Give uses of ceramics and mica as insulating materials.
9. Give properties and uses of plastic insulating materials.
10. How insulators are classified on the basis of their physical state. Write two examples in each case.

11. Separate the insulators from the following:
Air, Silver, wood, copper, germanium, mica, kerosene oil, carbon.

12. Give four important uses of insulators.

Q. Encircle the correct answer from the following MCQ's.

- (a) solid
 - (b) liquid
 - (c) gaseous
 - (d) semi solid

7 Mica can be used safely upto.....°C

8. prohibit the passage of electric current.

- (a) conductor
 - (b) insulator
 - (c) semiconductor
 - (d) super conductor

9. Sulphur Hexafluoride is stable upto.....°C

10. The dielectric constant of hydrogen gas is..... kilovolt per millimetre

11. Cotton, wool, silk and jute are the examples of

- (a) paper & card board (b) fibrous insulators
(c) wax (d) varnish

12.have very low electrical conductivity.

- (a) conductors
 - (b) super conductors
 - (c) semiconductors
 - (d) insulators

13.is a gaseous insulator.

14. The dielectric constant of nitrogen gas is..... kilovolt per millimetre

15. Copal, shellac and amber are the examples of

- (a) natural resins
 - (b) synthetic resins
 - (c) varnish
 - (d) all three

16. The dielectric constant of air is..... kilovolt per millimetre

17. The dielectric constant of rubber is..... kilovolt per millimetre

18. Ceramics, mica ,asbestos and glass are....insulating materials.

- (a) inorganic solids (b) organic solids
(c) inorganic liquid (d) organic liquid

19. The dielectric constant of PVC is.....kilovolt per millimetre

20. The dielectric constant of mineral oil is.....kilovolt per millimetre

LONG QUESTIONS

1. Define insulators and conductors. Write important properties of Insulators.
 2. Discuss solid, liquid and gaseous insulators with their examples.
 3. How insulators are classified?
 4. Discuss uses of solid, liquid and gaseous insulators.



Chapter 14

Semiconductors

Course contents**2 Hrs**

- 14.1 Introduction
- 14.2 Atomic structure of silicon and germanium
- 14.3 Bonding and conductivity
- 14.4 Energy bands in semiconductors

Learning outcomes:

After learning this chapter the students would be able to:

- 14.1 Define semiconductors
- 14.2 Draw the atomic structure of silicon and germanium
- 14.3 Describe the process of bonding and conductivity in semiconductors and conductors.
- 14.4 Explain energy bands in semi conductors

INTRODUCTION:

Today is the world of electronics that is electronic media, print media, transit media and mobile technology. Semiconductors are the basic component of these devices. Moreover these are extensively used in other electronic devices like solar cells, diodes etc. These have also revolutionised the information technology (IT), computer technology, industrial controllers, medical technology, space technology, life sciences, physics and war

technology. Integrated circuit (IC), calculators, watches, radio, TV, VCR, etc also comprises semiconductor.

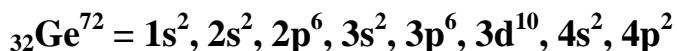
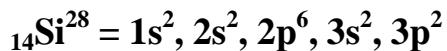
Semiconductors:

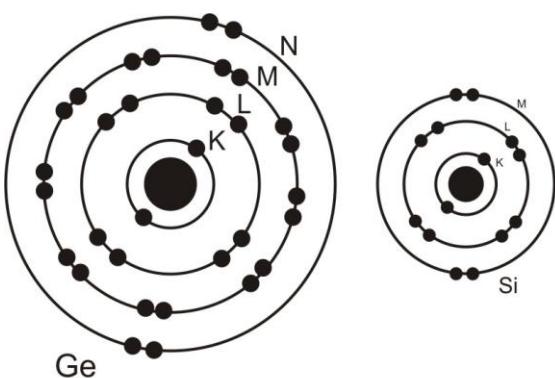
Semiconductors are the materials in which the electrical properties lie in between the conductor and insulators. Or the substances in which the energy gap or forbidden band is small between the filled energy band and the next higher permitted band are called *semiconductors*. Or

Any materials that have almost an empty conduction band and almost filled valence band with a narrow energy gap or forbidden band separating the two are called *semi-conductors*. The resistivity of semiconductors is 10^4 ohm-metre. These have four electrons in their outermost shell. The conductivity of semiconductors increases with the increase in temperature. For example Silicon, Germanium and Tellurium etc are semiconductors.

Electronic structure of Si & Ge:

Both the Silicon (Si) and Germanium (Ge) are the members of IV-A group that is carbon family. The atomic number of Si is 14 and the atomic mass is 28. It has 14 total electrons, first orbit carries 2 electrons, 2nd orbit 8 and 3rd orbit have 4 electrons. The atomic number of Ge is 32 and the atomic mass is 72. It has 32 total electrons, first orbit carries 2 electrons, 2nd orbit 8, 3rd orbit 18 and 4th orbit have 4 electrons. These have half filled valence shell that is 4 electrons in the outer most shell. These can form four covalent bonds with each other or with some other element to form SP^3 hybridised tetrahedral compounds. Their conductivity can be increased or decreased by doping them with the elements of 3rd or 5th group like boron or arsenic. Their electronic configuration is given below;



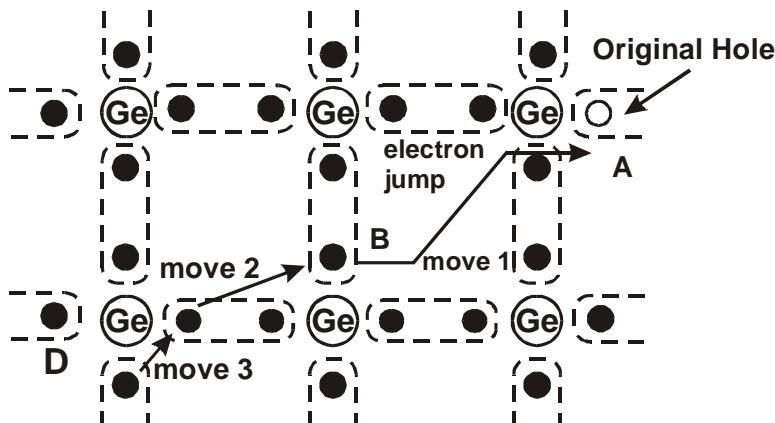


Electron Cloud Model of Ge & Si

BONDING AND CONDUCTIVITY IN SEMICONDUCTORS:

The conductivity of the semiconductors decreases with the decrease in temperature. In other words a semiconductor will be an insulator at 0K [zero Kelvin], as the valence electron of every atom is attached to the nucleus but at higher temperature or at 25°C the atoms absorb heat energy. The electrons in the crystals of semiconductors break to some extent due to their thermal agitation to form some new bonds.

Similarly a semiconductor can be converted into conductor with the increase of temperature, high voltage or photon bombardment. This results in the breakage of existing bonds. When a bond is broken a free electron is obtained and as a result a '**hole**' is produced. This hole shows the absence of an electron with the production of a +ive charge. This hole is mobile and is the carrier of electricity. For example when a hole in the structure of Si or Ge is formed at point 'A' an electron from another point 'B' moves towards 'A' and at 'B' a hole is created. Now another electron from point 'C' moves to fill hole at 'B' and thus a hole at 'C' is created. The movement of hole is similar to the conventional current and the movement of electrons is similar to the electric current. So simply a hole and electron will move in the opposite direction as shown in the figure.



Flow of electrons through semiconductors

The breakage of a bond in the semiconductors is called '*electron hole pair production*' and the conduction due to this electron hole pair production is called '*intrinsic conduction*'. The electron hole pair production is low at room temperature and is high at higher temperature.

Bonding and conductivity in conductors:

The number of valence electrons of a metallic conductor is less than 4 and these are loosely held due to the larger distance from the nucleus. These are always in random motion. These starts to move orderly in a specific direction with the supply of little amount of energy and thus help the current to flow. The atoms of the conductors are so close to each other that they mutually influence in such a way that their valence electrons form a single system of electronic arrangement, which behaves as a single entity. The electrons of the inner shells remain intact and do not participate in conductivity. These shells of the electrons or energy levels overlap to form a '*band*' of very closely spaced and slightly different energies.

The individual energies in these bands are so close to one another that these bands seem to be continuous. So any individual electron in a crystal would occupy its position only within that band. In other words the valence electrons participate in the conduction of electricity by virtue of their free movement and also by the up-gradation of the next higher empty conduction band.

ENERGY BANDS IN SEMICONDUCTORS:

The electrons possess different energy levels or shells in an atom. The electrons can move in the allowed orbital and cannot go to the other level. The electrons do not exist at the spaces between the different energy levels. The allowed energy levels are called *energy bands*. Some energy bands are very close to each other and look continuous as in conductors. So simply solids can be electrically classified on the basis of energy bands that is conductors, insulators and semiconductors.

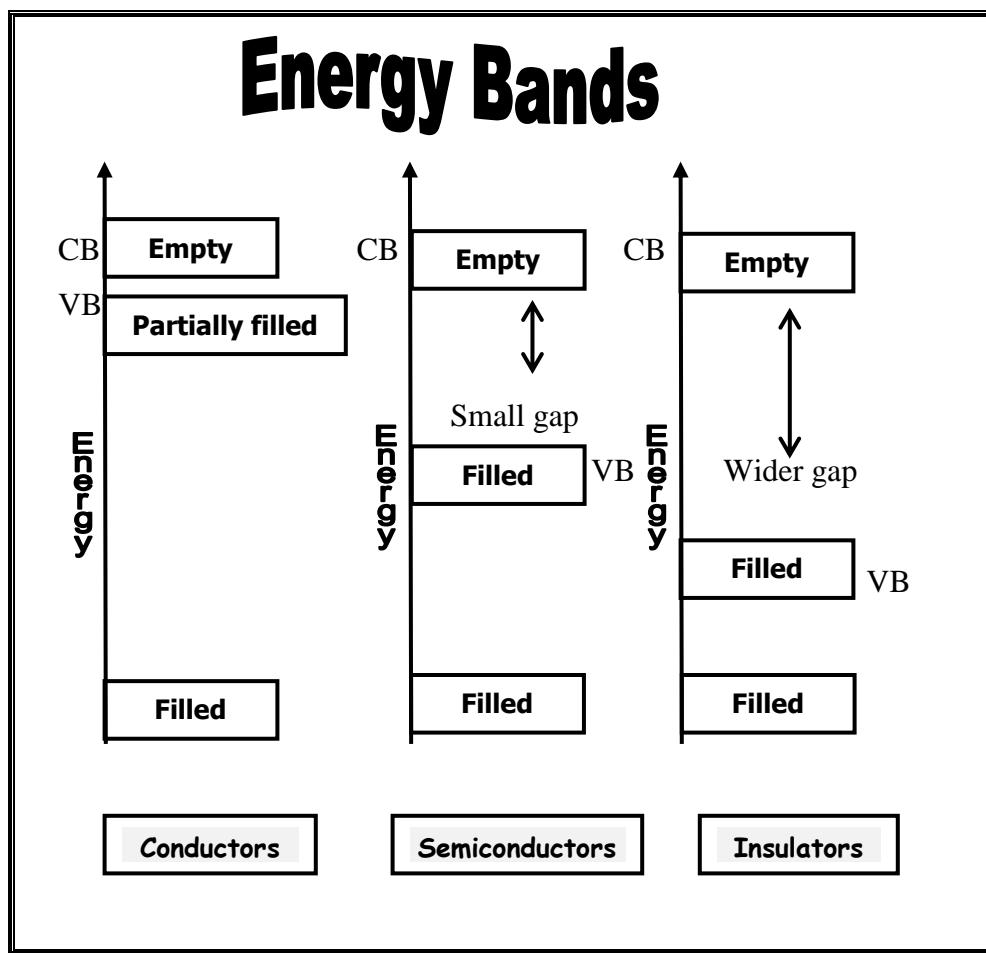
A completely filled band is called valence band. It has no free electrons. A partly filled band is called conduction band. It has free electrons to transfer charge and the energy of a filled band is called *fermi energy*. The fermi level separates the conduction band and valence band at 0K [zero Kelvin]. ‘VB’ stands for “*valence band*” and ‘CB’ for “*conduction band*” in this diagram. The flow of current is not possible in valence band where as it is possible in the conduction band. The conductivity of the insulators, semiconductors and conductors with the help of energy bands can be represented as:

Energy bands in conductor:

The highest energy conduction band is partly filled in the conductor. It carries no gap between conduction band and valence band and so here both these bands are joined together. In this band the electrons can be transformed by a minor current to high-energy state. That is why the flow of current is easier in conductors.

Energy bands in insulator:

In an insulator the number of electrons is very less and the highest energy conduction band is completely filled and the energy gap is also too wide that is electrons cannot jump to high-energy band. The gap between upper most conduction band in the insulators and the lowest valence band is more and as a result the possibility of conduction is rare.



Energy bands in the semiconductors:

The distance between valence band and its permissible higher energy band in the semiconductors is less. That is the valence electrons have to cover this distance to move into the conduction band. So a very little energy at the

room temperature is sufficient to allow electrons to go to the permissible or conduction bands to transfer charge as the electrons are free. So the current can pass. The conductivity of the semiconductors increases with the rise in temperature.

Valence band:

A completely filled band is called *valence band*. Or it is the energy band that comprises of valence electrons and may be completely or partially filled. The electrons of this band can move freely in the partially filled band.

Conduction band:

A partly filled band is called *conduction band*. It has free electrons to transfer charge. It is the next higher energy available forbidden band to receive the excited electrons. It may be empty or partially filled with electrons.

Forbidden band:

The forbidden energy region between the valence band and the conduction band is termed as '*forbidden band*' or the energy gap. Or the empty space present between the conduction band and the valence band is called forbidden band. This region is electron free. These exist only in the semiconductors and insulators. These are absent in conductors. For example the energy gap of silicon, germanium and tellurium is 1.115, 0.65, and 0.33 e.v. (Electron volts) respectively.

Conductivity of a semiconductor:

The conductivity of a semiconductor can be increased by

- i. By heating the semiconductor.
- ii. By the bombardment of the photon or light particles.
- iii. By doping the semiconductor with elements of group 3rd or 5th.

PROPERTIES OF SEMICONDUCTORS:

Following are the general properties of semiconductors;

1. The properties of semiconductors lies in-between the conductors and insulators. In other words these are metalloids.
2. Their electrical conductivity increases with the rise in temperature.
3. These become insulators at 0K (zero Kelvin).
4. These may be P-type or N-type depending upon the excess or shortage of the electrons.
5. These are the carrier of electric current or charge.
6. These are crystalline solids.
7. Their conductivity is less as compared to the metals.

Uses of semiconductors:

The semiconductors are used in: -

1. Electronic devices like radio, TV, IC, computer, calculator etc.
2. Diodes and rectifiers.
3. As cathode.
4. Photocells and solar batteries.
5. Measuring instruments like galvanometer etc.
6. Fluorescent light.
7. Medical technology.
8. Information technology.
9. Space technology.
10. Physics and war technology, and many more.

TYPES OF SEMICONDUCTORS:

Following are the two types of semiconductors:

1. Intrinsic semiconductors
2. Extrinsic semiconductors

1. Intrinsic semiconductors:

The pure semiconductor without any addition or additive is called intrinsic semiconductors. For example the use of Si and Ge as such. These are also called pure semiconductors.

2. Extrinsic semiconductors:

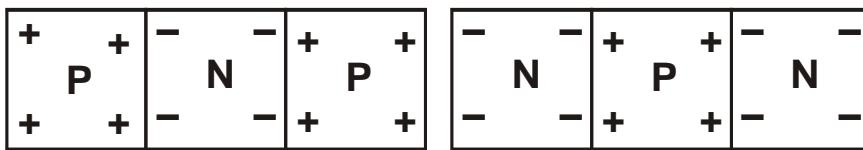
The semiconductor having some addition or additive is called extrinsic semiconductors. This process of mixing semiconductors with an additive is called '*doping*'. The process of doping is carried out to enhance the properties of semiconductors. Extrinsic semiconductors are also called impure semiconductors. For example doping of Si with boron etc. extrinsic semiconductors are of further two types:

a) N-type semiconductors:

When a semiconductor like Si is doped with a member of group 5th A having 5 valence electrons like antimony is called N-type semiconductors. Such doping is also called '*donor doping*'. Here four covalent bonds are formed between the two atoms while the 5th valence electron of antimony remains unbonded and this extra electron helps in the flow of electrons and hence charge. This type of flow of electrons is also called push electron strategy.

b) P-type semiconductors:

When a semiconductor like Si is doped with a member of group 3rd A having 3 valence electrons like boron is called P-type semiconductors. Such doping is also called '*acceptor doping*'. Here three covalent bonds are formed between the two atoms while the 4th valence electron of Si or Ge remains unbonded and thus a hole is created. So the other nearby electron moves to fill this hole. Similarly the movement of electrons results in the flow of current in which the hole and electron move in the opposite direction. This type of flow of electrons is also called pull electron strategy.



OBJECTIVE QUESTIONS

Q. Give answer to the following short questions:

1. Define semiconductors.
2. Give the four uses of semiconductors.
3. Give the electronic configuration of silicon and germanium.
4. What is the effect of temperature on the conductivity of semiconductors?
5. How the current is passed in the semiconductors?
6. How many electrons are there in the outer most shell of the semiconductors?
7. Define conductivity band and forbidden band.
8. How the conductivity of semiconductors can be increased?
9. Enlist the names of the types of the semiconductors,
10. Define p-type and n-type semiconductors.

Q. Select the correct answer from the following MCQ's.

1. Are the materials in which the electrical properties lie in between the conductor and insulator
 - (a) conductors
 - (b) insulator
 - (c) semiconductors
 - (d) all three
2. The resistivity of, is 10^4 ohm-meter.

- (a) intrinsic semiconductors (b) extrinsic semiconductors
(c) P-type (d) N-type
- 20. The process of mixing of a semiconductor with a member of group III-A or V-A is called**
- (a) Doping (b) P-type
(c) N-type (d) all three

LONG QUESTIONS

1. Draw the atomic structure of silicon and germanium
2. Describe the process of bonding and conductivity in semiconductors and conductors.
3. Explain energy bands in semi conductors



Chapter 15

Etching Process

Course Contents:**2 Hours**

- 15.1 Understand the etching process.
- 15.2 The process and its aims
- 15.3 Etching reagents
- 15.4 Application of process

Learning Out Comes:

After learning this chapter, students would be able to

- 15.1** Define Etching process and its aims
- 15.2** Enlist the Chemicals / reagents used in the process
- 15.3** Explain the uses of the process in the Technology

Introduction:

The process of etching is very important in the electronics technology because it provides a convenient method for the production of various circuits and chips. It is also used in the production of printing plates and carving designs on metals.

Etching:

Etching is the process in which certain chemicals eat up or corrode away certain materials like glass, metals etc as a result of which a design or drawing on the surface of the metal is produced. Or it is the process of engraving a design on metallic plates or glass etc by eating out a permanent impression with the help of acids or other corrosive chemicals.

Types of Etching:

Following are the prominent types of etching;

1. Chemical etching:

This is the most commonly etching method. Here some corrosive materials or chemicals are used to eat up some metal or glass. The corrosive materials or chemicals corrode only the naked parts. The type of the corrosive materials or chemicals used depends upon the material being carved, and the depth of etching required. Also the time of the etching varies as per need. For example HF and HNO₃ are widely used for chemical etching.

2. Soft ground etching:

In some cases soft-etching ground is prepared with soot or carbon black on the plate, and the required design or drawing is traced on the paper with lead pencil. Etching is affected below the paper by removing the resist and creating an impression of the design. The naked surface is then etched with the suitable corrosive materials or chemicals.

3. Electrolytic etching:

This process is also called as *anode etching* or *Electro-typing*. It is basically used for the preparation of decorated articles and printing plates. The impression of the design is carved on the wax, and is made conductor by the spray of graphite. This block is made as *cathode* and Cu as *anode* dipped in the copper sulphate solution. With the passage of electricity, a beautiful coating of Cu is achieved on the block.

4. Aquatint:

It is another type of etching in which resinous ground etch is used. In this method the microscopic blobs produced by acids are controlled, and are used to produce a number of light and dark shades.

Etching materials:

Following materials are used for etching;

1. Base material:

The base material used for the etching process is glass, and different metal plates.

2. Resists:

The ground forming substances or resist is wax, varnish, enamel, soot, carbon or nail polish etc.

3. Etching needle:

It may be lead pencil, etching or steel needle.

4. Etching reagents:

A number of reagents are available as described earlier and can be used as per need.

The process of etching:

Following are the major steps involved in the etching process;

1. Preparation of the plate:

The plate or article, on which etching is to be made, taken of desired size, cleaned thoroughly and then a uniform layer of some ground forming substance or a “*resist*” like wax, varnish or soot etc, is applied evenly.

2. Drawing of a sketch or design:

After the preparation of plate the specific design or drawing is sketched out on the plate by removing the resist material with the help of etching needle or with some suitable pen. The beauty of the etching depends upon the neatness and clarity of the design.

3. Etching:

The plate with drawing is now dipped into some corrosive material. Then the plate is kept immersed for proper time for good results. Only the open surface is corroded while the surface with resist does not corrode at all.

4. Removal of the resist:

When the reaction is completed as per need the resist material is removed by dissolving it in a suitable solvent like thinner or turpentine oil etc.

5. Washing, rinsing and drying:

After the removal of resist the plate is thoroughly washed with warm water and finally rinsed with alcohol and dried.

Aim of the etching process:

The main object of the etching process is to engrave a design or drawing on the smooth metallic or glass plates by the action of some corrosive materials. Nowadays it is commonly used for the preparation of printing plates and also producing decorative carvings and designs on the metal or glass articles. It is used recently in the production of electronic circuit boards, motherboards and microchips.

Etching reagents or chemicals:

These are the chemicals applied for the etching on metallic or glass plates. These eat up the naked parts of the plate. Following are the major etching reagents or chemicals used;

1. Nitric acid (HNO₃):

This is one of the most commonly used strongest etching reagents. It is used for steel etching. An effective and moderate preparation is as follows;

Nitric acid	=	1 – 5mL
Alcohol	=	100mL
Picric acid	=	1%

2. Ferric chloride and hydrochloric acid:

This etching reagent (FeCl₃ + HCl) is used for the etching of hard materials like stain less steel etc. An effective and moderate preparation is as follows;

Ferric chloride	=	5g
Hydrochloric acid	=	50mL
Water	=	100mL

3. Ammonium molybdate [(NH₄)₂MoO₄]:

It is fast reacting and wide range reagent and is prepared as follows;

Molybdic acid	=	100g
Nitric acid	=	60mL
Ammonium hydroxide	=	140mL
Water	=	240mL

4. Ammonium sulphate [(NH₄)₂SO₄]:

It is a multipurpose reagent and is effectively used in hot conditions. An effective and moderate preparation is as follows;

Ammonium sulphate	=	10g
Water	=	90mL

5. Ammonium hydroxide and hydrogen peroxide [NH₄OH + H₂O₂]:

It is an important reagent used for the etching of Cu and copper alloys. An effective and moderate preparation is as follows;

Ammonium hydroxide	=	5 parts
Hydrogen peroxide	=	2 – 5 parts
Water	=	5 parts

6. Palmerton reagent (Cr₂O₃ + Na₂SO₄):

It is an effective etching reagent having the following composition;

Chromium oxide	=	200g
Sodium sulphate	=	15g
Water	=	1000mL

7. Hydrofluoric acid (HF):

This is a very corrosive material and active reagent, and is used in the etching of glass. It is mostly used as 0.5%. Its composition is;

Hydrofluoric acid	=	0.5 mL
Water	=	99.5mL

8. Picric acid [C₆H₂(NO₂)₃OH]:

This reagent is used in the concentrated form, having the following composition;

Picric acid	=	113g
Alcohol	=	100mL

Applications of the etching process:

The major applications of the etching process are: -

1. Etching is widely used in the preparation of printing plates.
2. It is used to beautify the metallic plates by engraving designs and drawings on it.
3. It helps us in the comparative study of the metals and their properties.

4. This process prepares the electronic circuits.
5. The advanced etching process is preparing microchips.
6. Glass sheets are being carved with flowers and designs by the etching process.
7. Coloured metals and alloys like copper, zinc, and brass etc are cleaned by this process.
8. This process is also used to impart some specific colours to the metals like brown shade to iron and steel, white shade to bronze and brass etc.

OBJECTIVE QUESTIONS

Q. Give answer to the following short questions:

1. Describe etching process.
2. Describe the general use of etching.
3. Write down the name of the steps used in the etching process.
4. What is meant by etching reagents? Give two examples.
5. Which chemical is used for the etching of glass? Write its composition.
6. Which chemical is best suited for the etching of steel? Write its composition.
7. Write down the composition of picric acid.
8. Give the names of the types of etching.
9. Write down the list of the materials used for the etching process.
10. Which chemical is used for the etching of copper and copper alloys? Write its composition.

Q. Select the correct answer from the following MCQ's.

- 1. The process in which certain chemicals eat up or corrode away certain materials like glass, metals etc is called**
(a) etching process (b) metallurgy(c) electroplating (d) all three
- 2. It is the process of engraving a design on metallic plates or glass etc with the help of acids or other corrosive chemicals**
(a) etching process (b) metallurgy(c) electroplating (d) all three

- 3. It is the process in which a design or drawing on the surface of the metal is produced which certain chemicals**

(a) etching process (b) metallurgy (c) electroplating (d) all three

4. Is a convenient method for the production of various circuits and chips in the electronics technology

(a) etching process (b) metallurgy (c) electroplating (d) all three

5. Is used to engrave a design or drawing on the smooth metallic or glass plates

(a) etching process (b) metallurgy (c) electroplating (d) all three

6. The etching process consists of steps

(a) 4 (b) 5 (c) 6 (d) 7

7. A uniform layer of some ground forming substance or resist of, is used for the preparation of plate in the etching process.

(a) wax (b) varnish (c) lamp black (d) all three

8. Is used to sketch a design on the etching plate

(a) etching needle (b) ball point (c) brush (d) chalk

9. In the, process only the open surface is corroded while the surface having resist is not damaged

(a) etching process (b) metallurgy (c) electroplating (d) all three

10. Is used to remove resist from the etched plate

(a) thinner (b) alcohol (c) turpentine oil (d) all three

11. Etching reagent is used for the etching process

(a) Nitric acid (b) ammonium molybdate
(c) ferric chloride & hydrochloric acid (d) all three

12. Number of NO₂ groups present in one formula unit of Picric acid is

(a) 2 (b) 3
(c) 4 (d) 5

13. Is used for the etching of steel

14. Hard substances like stainless steel etc can be etched with the help of

15 The mixture of chromium oxide and sodium sulphate is commonly called as

- (a) Ammonium sulphate (b) ammonium hydroxide & hydrogen peroxide
(c) palmerton reagent (d) all three

16 used for the etching of glass

- (a) hydrofluoric acid (b) hydrochloric acid (c) picric acid (d) all three

17 The type of etching that have resist made up of varnish is called

18 Is also called anode etching or electro-typing

- (a) aquatint (b) chemical etching (c) electrolytic etching (d) no one

19 The comparative study of metals can be carried out with the help of

- (a) etching process (b) metallurgy (c) electroplating (d) all three

20 The preparation of base or basic plate is the most important step in the

- (a) etching process (b) metallurgy (c) electroplating (d) all three

LONG QUESTIONS

- Q. Explain the process of etching.

Q. Describe the types of etching. Discuss any one type in detail.

Q. What is an etching reagent? Give four reagents, their composition and uses.

Q. What are the uses of etching process?



Syllabus

COURSE OUTLINE

COURSE CODE Ch-132 (APPLIED CHEMISTRY)

Tech. Electrical, Electronics, Biomedical, Computer and
Computer Information

1. Introduction

- 1.1 The scope and significance of the subject
- 1.2 Orientation with reference to this technology
- 1.3 Terms used & units of measurements in the study of chemistry

2. Fundamental concepts of chemistry

- 2.1 Symbols, Valency, Radicals, Formulas
- 2.2 Chemical reactions & their types
- 2.3 Balancing of equations by ionic method

3. Atomic structure

- 3.1 Sub-atomic particles
- 3.2 Bohr's atomic model
- 3.3 The periodic classification of elements and periodic law
- 3.4 General characteristic of a period and group

4. Chemical bond

- 4.1 Nature of chemical bonds
- 4.2 Electrovalent bond with examples
- 4.3 Covalent bond (Polar and non-polar, sigma & Pi bonds with examples)
- 4.4 Co-ordinate bond with examples

5. Solids and liquids

- 5.1 The liquid and solids state
- 5.2 Liquids and their general properties (Density, Viscosity, Surface tension, capillary action etc.)
- 5.3 Solid and their general properties
- 5.4 Crystals of Si and Ge
- 5.5 Crystal structure of solids

6. Water

- 6.1 Chemical nature and properties
- 6.2 Impurities
- 6.3 Hardness of water (types, causes & removal)
- 6.4 Scales of measuring hardness (Degrees Clark, French, PPM, mg/litre)
- 6.5 Boiler feed water, scales and treatment
- 6.6 Sea-water desalination, sewage treatment

7. Acids, bases and salts

- 7.1 Definition with examples
- 7.2 Properties, their strength, basicity & acidity
- 7.3 Salts and their classification with examples
- 7.4 pH – Value and scale
- 8. Oxidation & reduction**
 - 8.1 The process with example
 - 8.2 Oxidizing and reducing agents
 - 8.3 Oxides and their classifications
- 9. Nuclear chemistry**
 - 9.1 Introduction
 - 9.2 Radioactivity (Alpha, beta and gamma rays)
 - 9.3 Half life process
 - 9.4 Nuclear reaction & transformation of elements
 - 9.5 Isotopes and their uses
- 10. Alloys**
 - 10.1 Introduction with need
 - 10.2 Preparation and properties
 - 10.3 Some important alloys and their composition
- 11. Corrosion**
 - 11.1 Introduction with causes
 - 11.2 Types of corrosion
 - 11.3 Rusting of iron
 - 11.4 Protective measure against corrosion
- 12. Electro chemistry**
 - 12.1 Ionisation and Arrhenius theory of Ionisation
 - 12.2 Electrolytes and electrolysis
 - 12.3 Faraday's law and numericals related to them
 - 12.4 Application of electrolysis (Electroplating etc.)
 - 12.5 Electro chemical cells
- 13. Electrical insulating materials**
 - 13.6 Introduction
 - 13.7 Solids insulators with chemical nature
 - 13.8 Liquid insulators with chemical nature
 - 13.9 Gaseous insulators with chemical nature
 - 13.10 Uses and their classification
- 14. Semi-Conductors**
 - 14.1 Introduction
 - 14.2 Atomic structure of silicon and germanium
 - 14.3 Bonding & Conductivity
 - 14.4 Energy bonds in a semiconductor
- 15. Etching process**
 - 15.1 The process and its aims
 - 15.2 Etching reagents
 - 15.3 Applications of processes