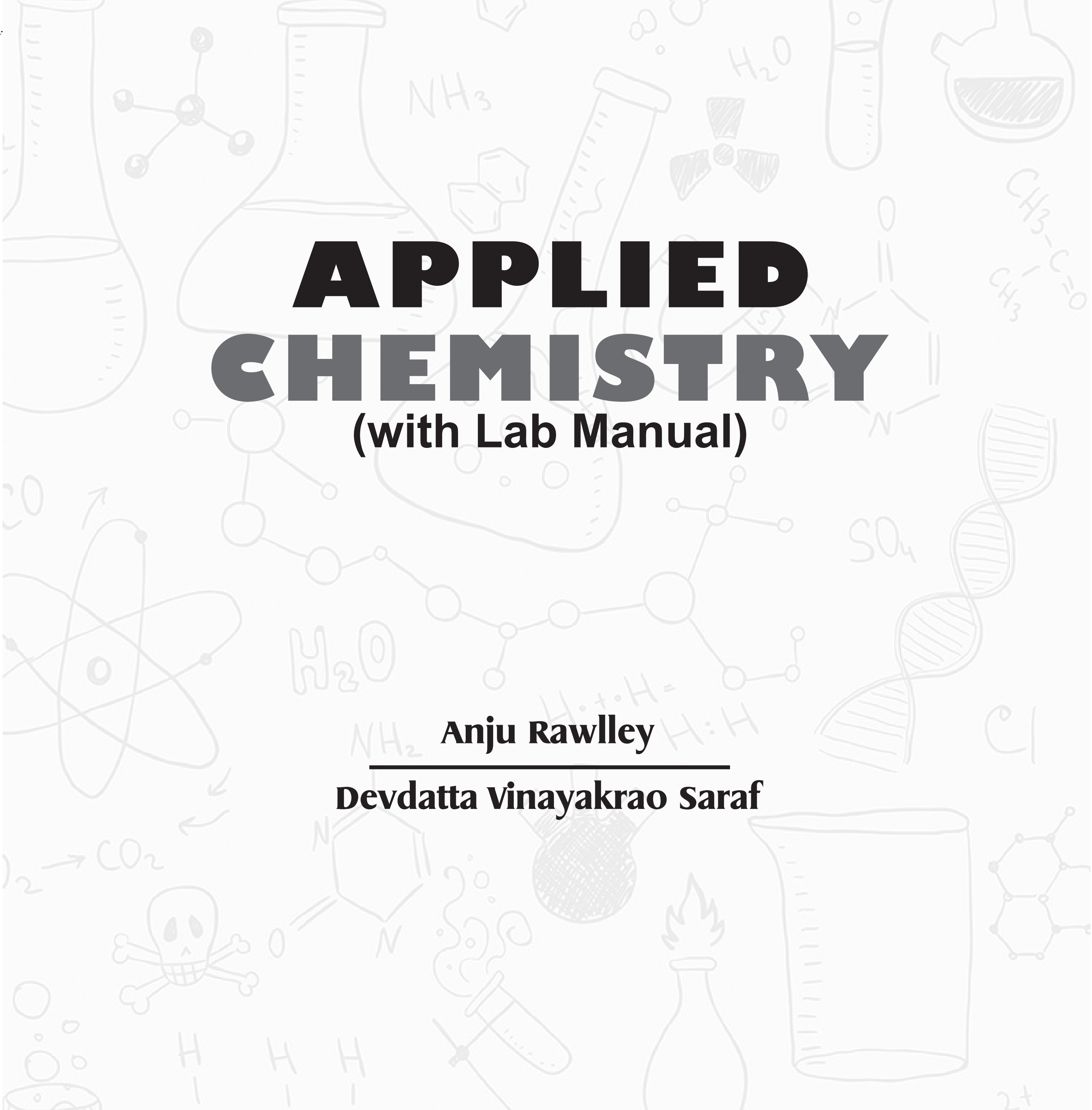

APPLIED CHEMISTRY

(with Lab Manual)

Anju Rawlley

Devdatta Vinayakrao Saraf

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FOREWORD

Engineering has played a very significant role in the progress and expansion of mankind and society for centuries. Engineering ideas that originated in the Indian subcontinent have had a thoughtful impact on the world.

All India Council for Technical Education (AICTE) had always been at the forefront of assisting Technical students in every possible manner since its inception in 1987. The goal of AICTE has been to promote quality Technical Education and thereby take the industry to a greater heights and ultimately turn our dear motherland India into a Modern Developed Nation. It will not be inept to mention here that Engineers are the backbone of the modern society - better the engineers, better the industry, and better the industry, better the country.

NEP 2020 envisages education in regional languages to all, thereby ensuring that each and every student becomes capable and competent enough and is in a position to contribute towards the national growth and development.

One of the spheres where AICTE had been relentlessly working from last few years was to provide high-quality moderately priced books of International standard prepared in various regional languages to all it's Engineering students. These books are not only prepared keeping in mind it's easy language, real life examples, rich contents and but also the industry needs in this everyday changing world. These books are as per AICTE Model Curriculum of Engineering & Technology – 2018.

Eminent Professors from all over India with great knowledge and experience have written these books for the benefit of academic fraternity. AICTE is confident that these books with their rich contents will help technical students master the subjects with greater ease and quality.

AICTE appreciates the hard work of the original authors, coordinators and the translators for their endeavour in making these Engineering subjects more lucid.

(**Anil D. Sahasrabudhe**)

ACKNOWLEDGEMENT

The author(s) are grateful to AICTE for their meticulous planning and execution to publish the technical book for Diploma Engineering students.

We sincerely acknowledge the valuable contributions of the reviewer of the book Prof. Sunita Mukesh Patil, for making it students' friendly and giving a better shape in an artistic manner.

This book is an outcome of various suggestions of AICTE members, experts and authors who shared their opinion and thoughts to further develop the engineering education in our country.

It is also with great honour that we state that this book is aligned to the AICTE Model Curriculum and in line with the guidelines of National Education Policy (NEP) -2020. Towards promoting education in regional languages, this book is being translated in scheduled Indian regional languages.

Acknowledgements are due to the contributors and different workers in this field whose published books, review articles, papers, photographs, footnotes, references and other valuable information enriched us at the time of writing the book.

Finally, we like to express our sincere thanks to the publishing house, M/s. Khanna Book Publishing Company Private Limited, New Delhi, whose entire team was always ready to cooperate on all the aspects of publishing to make it a wonderful experience.

Anju Rawlley
Devdatta Vinayakrao Saraf

PREFACE

Chemistry has been used for understanding and solving the intricacies of life. The advancement in chemistry is closely associated with the well being of all human beings and has made the life simpler and comfortable.

The textbook on "Applied Chemistry" has been developed as per AICTE model curriculum. This book is written, keeping in mind that basic concepts of chemistry should be comprehended in depth by budding diploma engineers, as these concepts may be applied in many of the engineering applications in industries and day to day life. The present text book is a sincere efforts in this direction.

Efforts have been made to make this book useful and interesting for learning, in self-learning mode. The structure of the textbook is comprehensive, wherein sixteen practical exercises are integral part of each theory units, from one to five.

Key feature of the book is that the text is presented in a very simple way with illustrations, examples, tables, flow charts, self-assessment questions with their solutions. Micro projects, points/issues for the creative inquisitiveness and curiosity, know more, video links, case study and summary points are integral part of different units to facilitate the students to develop the attitude of scientific inquiry, investigate the cause and effect relationship, systematic, scientific &logical thinking, ability to observe, analyse and interpret. All these abilities are essentially needed by diploma engineering passouts in the world of work.

Details of practicals listed in the curriculum of each unit are mentioned in a systematic format for ease of performance and implementation by students, laboratory personnel and teachers. Laboratory practical format is comprising of practical significance, relevant theory, stepwise procedure, safety precautions, sample probing questions for viva- voce etc. To meet the requirement of outcome based education (OBE) and outcome based assessment (OBA), criterion referenced testing (CRT) have been used as an integral part of assessment in each practical. For this, specific and measurable criteria of process and product assessment with their percentage weightage is included in each experiment. This would enable students, teachers and evaluators to know the criterion of performance and assessment of each experiment for attainment of out comes.

While every care has been taken to bring out this textbook error free. Nevertheless, there could inevitably be occasional errors. It would be our great pleasure to know from readers to make necessary modifications. Moreover, suggestions are welcome for the improvement of the book.

Anju Rawlley
Devdatta Vinayakrao Saraf

OUTCOME BASED EDUCATION

Though, there are many challenges and issues in implementation and assessment of Outcome Based Education (OBE) and Outcome Based Curriculum (OBC), but the management and teachers need to ensure that the programme outcomes, as stated by NBA, for diploma engineering programme should be developed by the students, at the exit point of the diploma programme,through effective implementation and assessment of outcomes of different courses. The seven programme outcomes of the diploma engineering programme are as follows:

PO1. **Basic and Discipline Specific Knowledge:** Apply knowledge of basic mathematics, science and engineering fundamentals and engineering specialization to solve the engineering problems.

PO2. **Problem Analysis:** Identify and analyse well-defined engineering problems using codified standard methods.

PO3. **Design/ Development of Solutions:** Design solutions for well-defined technical problems and assist with the design of systems components or processes to meet specified needs.

PO4. **Engineering Tools, Experimentation and Testing:** Apply modern engineering tools and appropriate technique to conduct standard tests and measurements.

PO5. **Engineering Practices for Society, Sustainability and Environment:** Apply appropriate technology in context of society, sustainability, environment and ethical practices.

PO6. **Project Management:** Use engineering management principles individually, as a team member or a leader to manage projects and effectively communicate about well-defined engineering activities.

PO7. **Life-Long Learning:** Ability to analyse individual needs and engage in updating in the context of technological changes.

COURSE OUTCOMES

After completion of the course the students will be able to:

CO-1: Solve various engineering problems applying the basic concepts of atomic structure, chemical bonding and solutions.

CO-2: Use relevant water treatment method to solve domestic and industrial problems.

CO-3: Solve the engineering problems using concepts of engineering materials and properties.

CO-4: Use relevant fuel and lubricants for domestic and industrial applications.

CO-5: Solve the engineering problems using concept of electrochemistry and corrosion.

Course Outcomes	Expected Mapping with Programme Outcomes (1-Weak Correlation; 2-Medium correlation; 3-Strong Correlation)						
	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**	**PO-7**
CO-1	3	2	1	1	2	1	1
CO-2	3	3	2	3	2	3	2
CO-3	3	2	3	3	3	2	2
CO-4	3	3	2	3	3	2	2
CO-5	3	2	2	2	2	2	2

ABBREVIATIONS AND SYMBOLS

List of Abbreviations

Abbreviations	Full form	Abbreviations	Full form
C.E.	Chemical Equivalent or Equivalent Weight	TAN	Total Acid Number
CO	Course Outcome	TEL	Tetra Ethyl Lead
EDTA	Ethylene Diamine Tetra Acetic acid	UO	Unit Outcome
HCV	Higher Calorific Value	VII	Viscosity Index Improvers
LCV	Lower Calorific Value	VM	Viscosity Modifiers
PO	Programme Outcome	Z or E.C.E.	Electrochemical Equivalent
RCC	Reinforced Cement Concrete		

LIST OF SYMBOLS

Symbols	Description
n	Principal Quantum Number
l	Angular Momentum or Azimuthal Quantum Number
m	Magnetic Quantum Number
m_s	Spin Quantum Number

Units Used

Abbreviations	Full form
B.Th.U/ft^3	British Thermal Units Per Cubic Foot
B.Th.U./lb	British Thermal Units Per Pound
Cals/g	Calories Per Gram
C.H.U./lb	Centigrade Heat Unit Per Pound
^{0}Cl	^{0}Clark
^{0}Fr	^{0}French
K	Kelvin
K cals / kg	Kilocalories Per Kilogram
Kcal/m^3	Kilocalories Per Cubic Meter
mg / L	Milligrams Per Litre
meq / L	Milliequivalent Per Litre
ppm	Parts Per Million
ppt	Precipitate

LIST OF FIGURES

Unit 1

Unit 2

Unit 3

Unit 4

Unit 5

LIST OF TABLES

Unit 1

Unit 2

Unit 3

Unit 4

Unit 5

Some Ionic Compounds (Electrovalent Compounds)

Sr.No	Name	Formula	Ions present
1.	Sodium Chloride	$NaCl$	Na^+ and Cl^-
2.	Potassium Chloride	KCl	K^+ and Cl^-
3.	Ammonium Chloride	NH_4Cl	NH_4^+ and Cl^-
4.	Magnesium Chloride	$MgCl_2$	Mg^{2+} and Cl^-
5.	Calcium Chloride	$CaCl_2$	Ca^{2+} and Cl^-
6.	Sodium Oxide	Na_2O	Na^+ and O^{2-}
7.	Magnesium Oxide	MgO	Mg^{2+} and O^{2-}
8.	Calcium Oxide	CaO	Ca^{++} and O^{2-}
9.	Aluminium Oxide	Al_2O_3	Al^{3+} and O^{2-}
10.	Sodium Hydroxide	$NaOH$	Na^+ and OH^-
11.	Copper Sulphate	$CuSO_4$	Cu^{2+} and SO_4^{2-}
12.	Calcium Nitrate	$Ca(NO_3)_2$	Ca^{2+} and NO^{3-}
13.	Aluminium Chloride	$AlCl_3$	Al^{3+} and Cl^-

Some Covalent Compounds

Sr. No.	Name	Formula	Present Atoms
1.	Methane	CH_4	C and H
2.	Ethane	C_2H_6	C and H
3.	Ethylene	C_2H_4	C and H
4.	Ethyne (Acetylene)	C_2H_2	C and H
5.	Water	H_2O	H and O
6.	Ammonia	NH_3	N and H
7.	Ethyl Alcohol (Ethanol)	C_2H_5OH	C, H and O
8.	Hydrogen Chloride Gas	HCl	H and Cl
9.	Hydrogen Sulphide Gas	H_2S	H and S
10.	Carbon Dioxide	CO_2	C and O
11.	Carbon Disulphide	CS_2	C and S
12.	Carbon Tetrachloride	CCl_4	C and Cl
13.	Glucose	$C_6H_{12}O_6$	C, H and O
14.	Cane Sugar	$C_{12}H_{22}O_{11}$	C, H and O
15.	Urea	$CO(NH_2)_2$	C, O, N and H
16.	Benzene	C_6H_6	C and H
17.	Hydrogen Gas	H_2	H
18.	Chlorine Gas	Cl_2	Cl
19.	Oxygen gas	O_2	O

Some Common Salts Present in Water

Sr.No	Name	Formula	Ions present
1	Calcium Carbonate	$CaCO_3$	Ca^{2+} and CO_3^{2-}
2	Magnesium Carbonate	$MgCO_3$	Mg^{2+} and CO_3^{2-}
3	Calcium Bicarbonate	$Ca(HCO_3)_2$	Ca^{2+} and HCO_3^-
4	Magnesium Bicarbonate	$Mg(HCO_3)_2$	Mg^{2+} and HCO_3^-
5	Calcium Chloride	$CaCl_2$	Ca^{2+} and Cl^-
6	Magnesium Chloride	$MgCl_2$	Mg^{2+} and Cl^-
7	Calcium sulphate	$CaSO_4$	Ca^{2+} and SO_4^{2-}
8	Magnesium sulphate	$MgSO_4$	Mg^{2+} and SO_4^{2-}
9	Ferrous Chloride	$FeCl_2$	Fe^{2+} and Cl^-
10	Ferrous Sulphate	$FeSO_4$	Fe^{2+} and SO_4^{2-}
11	Manganese Chloride	$MnCl_2$	Mn^{2+} and Cl-
12	Manganese Sulphate	$MnSO_4$	Mn^{2+} and SO_4^{2-}
13	Calcium Silicate	$CaSiO_3$	Ca^{2+}, Si^{4+} and O_2^-
14	Magnesium Silicate	$MgSiO_3$	Mg^{2+}, Si^{4+} and O_2^-
15	Sodium Carbonate	Na_2CO_3	Na^+ and CO_3^{2-}
16	Sodium Sulphate	Na_2SO_4	Na^+ and SO_4^{2-}
17	Potassium Chloride	KCl	K^+ and Cl^-
18	Potassium Carbonate	K_2CO_3	K^+ and CO_3^{2-}
19	Potassium Sulphate	K_2SO_4	K^+ and SO_4^{2-}
20	Calcium Hydrogen Phosphates	$CaHPO_4$	Ca^{2+}, HPO_4^{2-}

GUIDELINES FOR TEACHERS

To implement Outcome Based Education (OBE), knowledge level and skill set of the students should be enhanced. Teachers should take a major responsibility for the proper implementation of OBE. Some of the responsibilities (not limited to) for the teachers in OBE system may be as follows:

- Within reasonable constraint, they should manoeuvre time to the best advantage of all students.
- They should assess the students only upon certain defined criterion without considering any other potential ineligibility to discriminate them.
- They should try to grow the learning abilities of the students to a certain level before they leave the institute.
- They should try to ensure that all the students are equipped with the quality knowledge as well as competence after they finish their education.
- They should always encourage the students to develop their ultimate performance capabilities.
- They should facilitate and encourage group work and team work to consolidate newer approach.
- They should follow Blooms taxonomy in every part of the assessment.

Bloom's Taxonomy

Level	Teacher should Check	Student should be able to	Possible Mode of Assessment
Creating	Students ability to create	Design or Create	Mini project
Evaluating	Students ability to Justify	Argue or Defend	Assignment
Analysing	Students ability to distinguish	Differentiate or Distinguish	Project/Lab Methodology
Applying	Students ability to use information	Operate or Demonstrate	Technical Presentation/ Demonstration
Understanding	Students ability to explain the ideas	Explain or Classify	Presentation / Seminar
Remembering	Students ability to recall (or remember)	Define or Recall	Quiz

GUIDELINES FOR STUDENTS

Students should take equal responsibility for implementing the OBE. Some of the responsibilities (not limited to) for the students in OBE system are as follows :

- Students should be well aware of each UO before the start of a unit in each and every course.
- Students should be well aware of each CO before the start of the course.
- Students should be well aware of each PO before the start of the programme.
- Students should think critically and reasonably with proper reflection and action.
- Learning of the students should be connected and integrated with practical and real life consequences.
- Students should be well aware of their competency at every level of OBE.

CONTENTS

Unit 3 : Engineering Materials **93-136**

1

Atomic Structure, Chemical Bonding and Solutions

UNIT SPECIFICS

This unit comprises of the following major topics :

- Atomic structure
- Chemical bonding
- Solution

The different concepts have been explained through examples for generating further curiosity and inquisitiveness and also developing creative problem solving abilities in the students, with the mention of their practical applications in the industries/day to day life.

Assessment for learning at different intervals within the unit, at different levels of cognitive domain is carried out by designing formative assessment questions.

For effective implementation of the outcome based curriculum in true spirit, wide spectrum of activities such as micro projects, assignments, industrial visits etc, are designed and integrated in the unit for the benefit and exposure of the students. Sample QR codes have been provided on various topics/sub topics for supplementary reading and reinforcing the learning.

RATIONALE

Diploma engineers need to understand the arrangement of all existing elements, the structural arrangement of fundamental particles, atoms and molecules. Theories put forward by different scientists in the form of laws and principles have been explained for understanding the structure of the atom.

The chemical bonds are important in human physiology. The proteins and carbohydrates needed for our body are all result of chemical bonding between atoms. Oxygen we breathe, medicines we need are result of chemical bonding between atoms. It helps to explain how atoms are held together in different types of structures.

The knowledge of chemical bonding and solution is extremely important to chemists, scientists, and every individual. Chemical bonding creates substances/compounds that everyone uses. It helps scientists to design new engineering materials and form chemical compounds with desirable properties for specific uses. Scientists could present 118 elements in the periodic table due to chemical bonding. While considering the future scenario, students have to work in different areas so as to comprehend the fundamental aspects such as bond formation and different anomalous behaviour of atoms, ions and molecules.

PRE-REQUISITES

Chemistry	:	Composition of matter
Mathematics	:	Basic algebra and geometry
Other	:	Basic ICT skills

UNIT OUTCOMES

List of outcomes of this unit are as follows :

U1-O1 Apply the different atomic theories, models and principles for structural illustration.

U1-O2 Write the electronic configuration of different elements.

U1-O3 Differentiate among the ionic, covalent and coordinate compounds based on the type of chemical bonding.

U1-O4 Prepare the solution of given concentration (Normality, Molarity)

Unit - 1 Outcomes	Expected Mapping of Unit Outcomes with the Course Outcomes (1- Weak Correlation; 2- Medium Correlation; 3- Strong Correlation)				
	CO-1	CO-2	CO-3	CO-4	CO-5
U1-O1	3	-	-	-	-
U1-O2	3	-	-	-	-
U1-O3	3	-	-	-	-
U1-O4	3	-	-	-	-

1.1 ATOMIC STRUCTURE

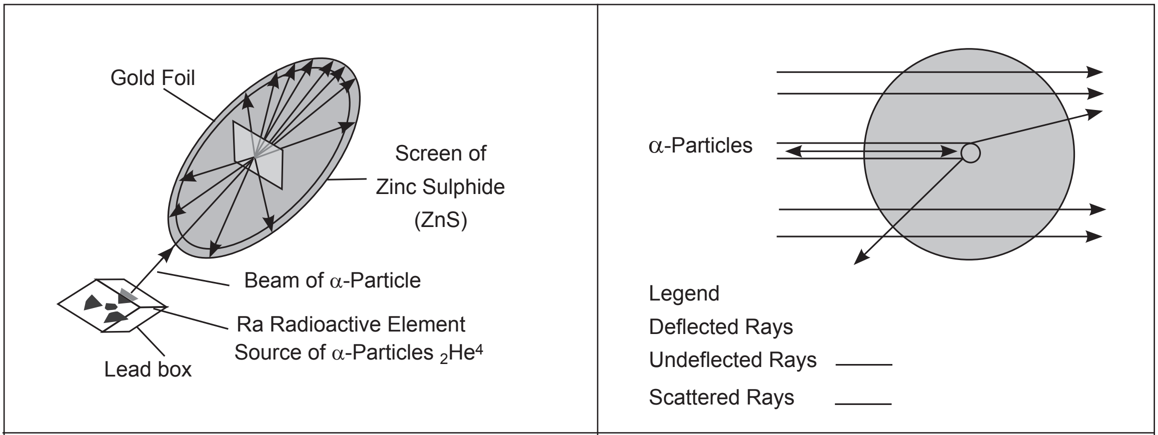
1.1.1 An Introduction

An atom is the smallest part of the existing universe. To understand the structure and arrangement of the smallest part of matter, thinkers and philosophers from all over the world put forward different theories for explaining the smallest particle of matter. In this unit, we will be learning about basic structure of atom, which is confirmed after performing different experiments.

Interesting fact : The structure of an atom explained by Bohr is just like our solar system where the sun is at the centre and planets are revolving around it.

1.1.2 Rutherford Model of an Atom

In the early 1900, scientists from different countries tried to explain the structure of an atom. J.J. Thomson discovered the presence of electron in an atom in 1897, still he was unable to predict the structure of an atom. J.J Thomson won the Noble Prize of 1906 for the discovery of electrons.



(a) Gold Foil Experiment

(b) Scattering of α- Rays through an Atom

Fig. 1.1 : Rutherford Experiment

Rutherford discovered the presence of proton in his famous gold foil experiment. Rutherford used Radium as a source of alpha particles which was placed inside the lead box. A beam of alpha particles bombarded on an ultra-thin gold foil and then the presence of undeflected, scattered and deflected alpha particles were recorded over zinc sulphide (ZnS) screen due to its fluorescent nature as shown in [Fig. 1.1(a)].

He concluded that all of the positive charge and the majority of the mass of the atom must be concentrated in a very small space in the centre of an atom, which he called the nucleus.[Fig. 1.1(b)].

Rutherford Model of an Atom

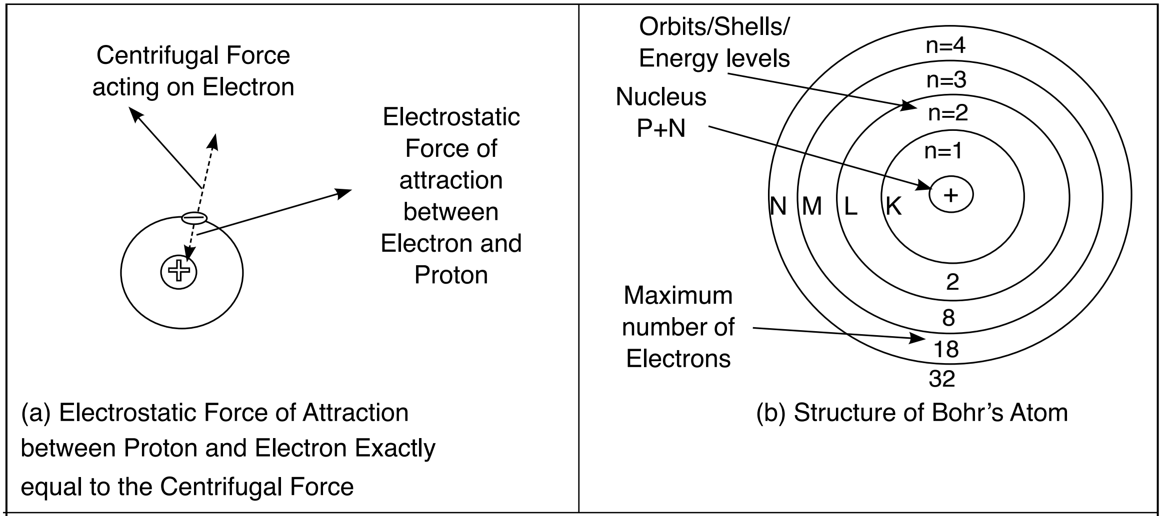
The nucleus is the dense, central core of the atom and is composed of protons and neutrons which contribute nearly all of the mass of the atom. The electrons are distributed around the nucleus and occupy most of the volume of the atom.

1.1.3 BOHR'S THEORY

Bohr proposed his atomic model to overcome the drawbacks of Rutherford's nuclear model. Bohr's atomic model is based on the following postulates.

- An atom consists of a dense positively charged central part known as the nucleus which is at rest.
- The nucleus contains protons and neutrons combinedly called nucleons.
- The fixed circular path in which electrons revolve around the nucleus is known as orbits or shells.

Bohr's Model



(a) Electrostatic Force of Attraction between Proton and Electron Exactly equal to the Centrifugal Force

(b) Structure of Bohr's Atom

Fig. 1.2 : Bohr's Representation of Forces acting on Electrons and Orbits in an Atom

- Stationary orbits or non-radiating orbits are those orbits in which electrons do not radiate energy i.e. they are permitted to rotate without loss of energy.
- Permitted shells or orbits are those for which the angular momentum of the electron is an integral multiple of $\frac{h}{2\pi}$ i.e. mvr $=n\left(\frac{h}{2\pi}\right)$, where n is a principal quantum number or

  shell number, momentum is nothing but the product of mass and velocity (mv), r is radius, h is Planks constant $h = 6.626 \times 10^{-34}$ J sec
- Angular momentum of an electron for n=1, 2, 3, 4…are respectively as

  $$mvr = 1\left(\frac{h}{2\pi}\right),\ mvr = 2\left(\frac{h}{2\pi}\right),\ mvr = 3\left(\frac{h}{2\pi}\right),\ mvr = 4\left(\frac{h}{2\pi}\right)\ldots$$
- The shape of orbit is circular. Orbits are designated by K, L, M, N…. or denoted as 1, 2, 3, 4…. from the nucleus as shown in [Fig. 1.2 (b)].
- The maximum capacity to accommodate electrons is given by formula $2n^2$, where n is orbit number.
- The electrostatic force of attraction between the nucleus and electron is exactly balanced by the centrifugal force as shown in [Fig. 1.2 (a)], that is why the electrons do not fall into the nucleus or do not go away from the orbit and hence the atom remains stable.

*SAQ 1	The capacity of the shell to accommodate the maximum number of electrons is given by the formula			
	1. $1/2n^2$	2. $2n^2$	3. $3/2n^2$	4. $4/2n^2$

Key : 2

SAQ 2	In the Rutherford experiment, the maximum number of undeflected particles represent that			
	1. maximum space of an atom is empty	2. maximum number of nucleus present in an atom	3. maximum number of positive charge present at the centre	4. maximum number of negative charge present at the centre

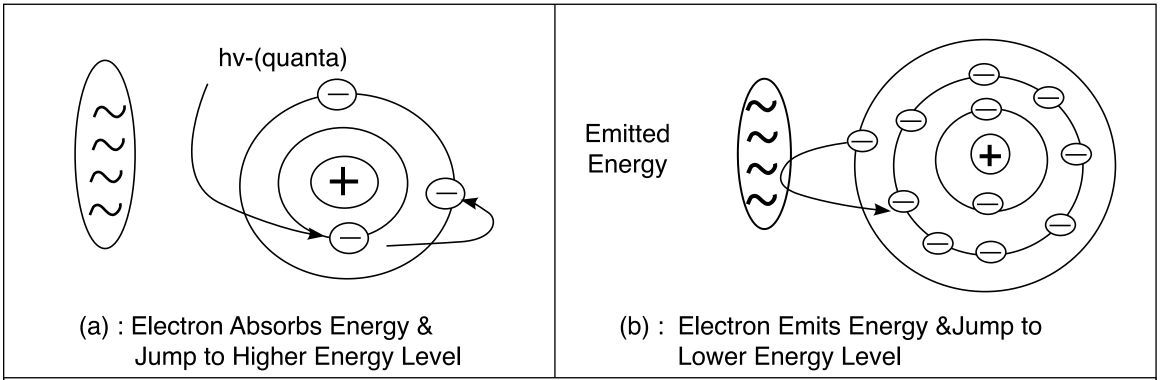
Key : 1

SAQ 3	According to Bohr's theory, the angular momentum of an electron for n = 4 is			
	1. $\frac{h}{2\pi}$	2. $\frac{2h}{2\pi}$	3. $\frac{4h}{3\pi}$	4. $\frac{2h}{\pi}$

Key : 4

*(*SAQ denotes Self Assessment Question)*

1.1.4 Hydrogen Spectrum Explanation Based on Bohr's Model of an Atom



(a) : Electron Absorbs Energy & Jump to Higher Energy Level

(b) : Electron Emits Energy &Jump to Lower Energy Level

Fig. 1.3 : Jumping of an Electron after Absorbing and Emitting the Energy

When the electron absorbs energy, the electron moves from the lower energy level to a higher energy level. Jumped electrons are known as excited electrons. As shown in [Fig. 1.3 (a)] when an electron emits energy, electrons jump from a higher energy level to a lower energy level. The emitted energy is the difference of energies between two energy levels i.e. hν=Energy of electron present in higher energy level - Energy of electron present in lower energy level. Absorbed energy or released energy is in the form of quanta or photon only. The excited electron cannot jump along with high energy to lower energy orbitals.

There is a difference in energies when an electron jumps from a higher energy level to a lower one. [Fig. 1.3 (b)]. When an electron emits energy it releases energy in the form of photons. i.e. E= hν. Due to loss of energy, there is a development of spectral lines of different frequencies which shows that distance between two different orbits is not equal.

As we move away from the nucleus, the energy of orbits goes on increasing, while the distance between the orbits goes on decreasing. Jumping of the electron from one orbit to another orbit results in the emission of energy known as the transition of the electron. Transition frequency emitted in the form of the photon is given by

$$\bar{\nu} = \frac{1}{\lambda} = R_H\left[\frac{1}{n_f^2} - \frac{1}{n_i}\right]$$

Where R_H is Rydberg's Constant, n_i is initial stationary orbit, n_f is final stationary orbit. The wave numbers $\bar{\nu}$ is reciprocal of the wavelength. Hence wave number of photons of the various spectral series are developed as shown in table 1.1 and [Fig. 1.4]. Bohr theory successfully accounts for the spectra of hydrogen and hydrogen like atoms like He^+, Li^{2+}, Be^{3+}, B^{4+}. Different spectrums are developed due to transition of electron from higher energy level to lower energy level. e.g. Lyman series is a spectral series for the transitions of electron from energy level 2 or 3 or 4 or… to first energy level. Similarly other series are developed (table 1.1)

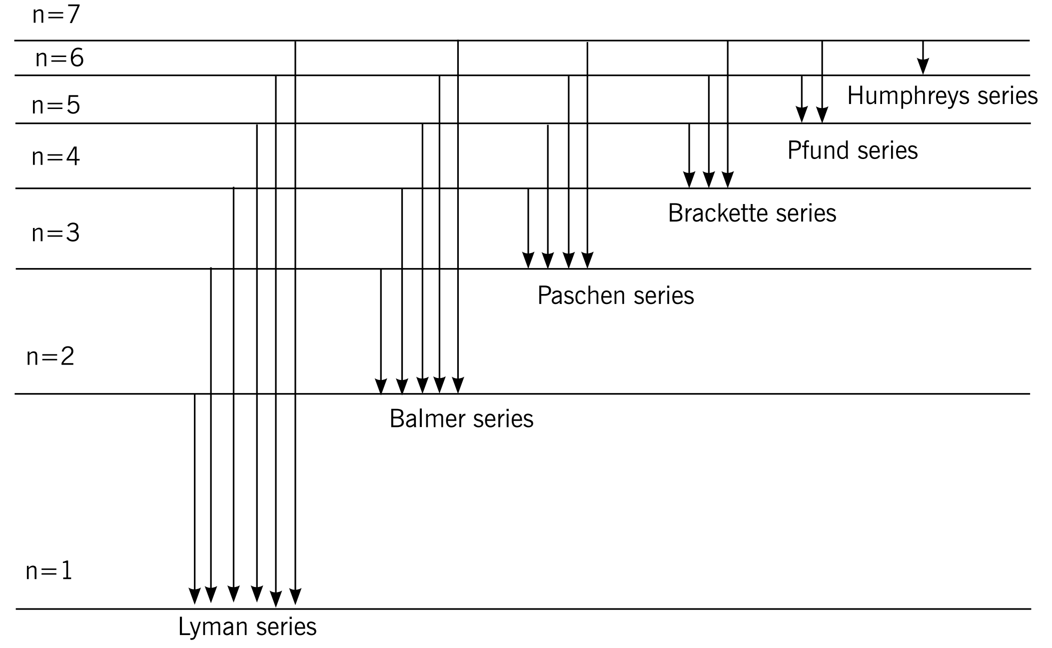


Fig. 1.4.: Hydrogen Spectrum Lines due to Jumping of Electrons

Table 1.1 : Appearance of Hydrogen Spectrum in Different Region

Name of Series	n_f Electrons Jumping at	≥ ni Electrons Jumping from	Appearing in Region
Lyman Series	1	2, 3, 4 ….	Ultraviolet region
Balmer Series	2	3, 4, 5, 6….	Visible region
Paschen Series	3	4, 5, 6, 7 …	Infrared region
Brackette Series	4	5, 6, 7,..	Infrared region
Pfund Series	5	6, 7,...	Infrared region
Humphreys Series	6	7,8,….	Infrared region

1.1.5 Heisenberg's Uncertainty Principle

> It is not possible to determine precisely the exact position and momentum of moving electron simultaneously.

Suppose Δx is uncertainty related to the position of an electron and Δp is the uncertainty related to the momentum of an electron.

Mathematically it is stated as$(\Delta x).(\Delta p) \geq \frac{h}{4\pi}$

when (Δx) is tremendously small we can predict the approximate position of the particle at the same time Δp i.e. uncertainty related to momentum will be more. where Δx is the uncertainty in position and Δp is the uncertainty in momentum (or velocity) of the particle. If the position of the electron is known with high degree of accuracy (Δx is small), then the velocity of the electron will be uncertain [Δp is large]. On the other hand, if the velocity of the electron is known precisely (Δp is small), then the position of the electron will be uncertain(Δx will be large). Heisenberg won the Noble prize in 1932 for the creation of quantum mechanics, the application of which has led to the discovery of the allotropic forms of hydrogen.

SAQ 4	"It is not possible to determine precisely the exact position and momentum of a small moving particle simultaneously " is			
	1. Orbital Concept	2. Aufbau Principle	3. Pauli's Exclusion Principle	4. Heisenberg's Uncertainty

Key: 4

1.1.6 Orbital Concept and Shapes of s, p, d and f Orbitals

An orbit, as proposed by Bohr, is a fixed circular path around the nucleus in which an electron moves. A precise description of this path of the electron is impossible according to the Heisenberg uncertainty principle.

> An atomic **orbital** thus represents a region in three-dimensional space around the nucleus where there is a maximum probability of finding an electron of specific energy.

There are four types of orbitals as follows :

s-Orbital

These orbitals are having spherical and non-directional shape [Fig. 1.5]. Each s orbital can accommodate 2 electrons in the opposite spin. One electron with +1/2 spin, another electron with - 1/2 spin. In another way one with upward spin and another with downward spin or one with clockwise spin another with counter-clockwise (anticlockwise spin). Size of 1s is less than 2s orbital; size of 2s is less than 3s orbital.

$\boxed{\uparrow\downarrow}$

Box Diagram

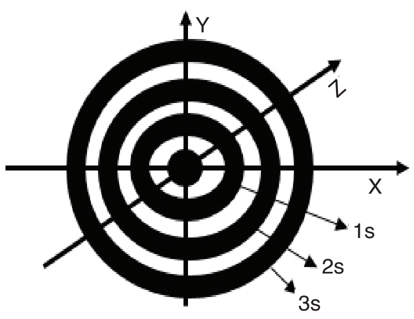


Fig. 1.5 : Shape of s-Orbitals

The empty region between two s-orbitals, where zero per cent probability of finding the electrons is known as the zero electron density region.

p-Orbital

There are three p- sub orbitals (px, py and pz) orbitals having dumb-bell shape [Fig. 1.6]. These orbitals are directional and along the axis orbital. Each p suborbital can accommodate 2 electrons in opposite spin hence the capacity of p orbital is 6 electrons. These sub orbitals are degenerate (having an equal amount of energy). If the lobe of the orbital is sprayed along the x-axis, then that orbital is called px orbital. Similarly if the lobe is sprayed along y-axis then that orbital is called py orbital and if lobe is sprayed along z-axis then that orbital is called pz orbital.

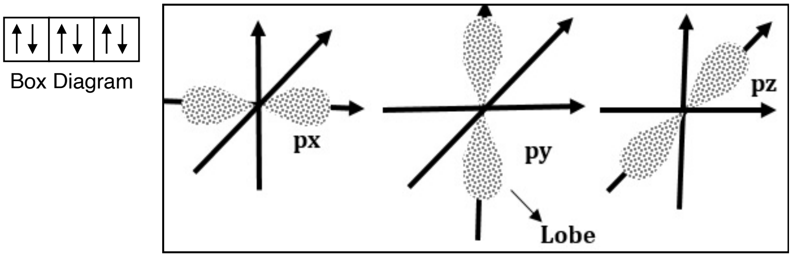


Fig. 1.6 : Dumbbell Shape of p-Orbitals

d-Orbital

There are five d- sub orbitals (dxy, dyz, dxz, $dx^2–y^2$ and dz^2) orbitals [Fig. 1.7]. d-orbitals are having the double dumb-bell shape or four-lobe planar structure. These orbitals are directional and along the axis orbital ($dx^2–dy^2$ and dz^2) as well as in between the axis orbitals (dxy, dyz and dxz). Each d sub orbital can accommodate 2 electrons in opposite spin hence the maximum capacity of d orbital to accommodate electrons is 10 electrons.

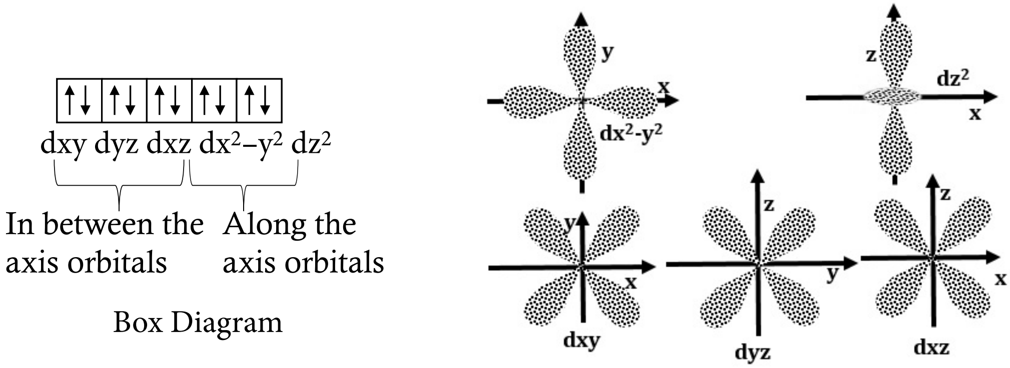


Fig. 1.7 : Double Dumbbell Shape of d-Orbitals

f-Orbital

- There are seven f- sub orbitals $fx(x^2-3y^2)$, $fy(3x^2-y^2)$,$fz(x^2-y^2)$,fxz^2, fyz^2, fz^3, fxyz

- f-orbitals are having a complicated shape.
- Each f-orbital are having seven f-sub orbitals hence capacity to accommodate electrons is 14 electrons.

1.1.7 Quantum Numbers

The Bohr model was a one-dimensional model that used one quantum number to describe the distribution of electrons in the atom. It explains the size of the orbit, which was described by the principal quantum number (n). Schrodinger's model allowed the electron to occupy three-dimensional space. It therefore required set of four quantum numbers, to describe the orbitals in which electrons can be found.

Four quantum numbers as principal quantum number(n) give information about main energy level; azimuthal quantum number (l)provides information about sub energy level; magnetic quantum number (m) gives information of orientation of sub-energy level and spin quantum number (ms) gives the direction of spin.

These four quantum numbers in an atom give the exact position of the electron, it is just like working of global positioning system (GPS) location or address, we can say that these quantum numbers give the exact location or address of electron.

(A) Principal Quantum Number (n)

- This quantum number is represented by the letter (n).
- This number gives information on the position of the electron as well as the energy associated with the electron.
- The values of 'n' are positive integral numbers as 1, 2, 3, 4…etc. corresponding to K, L, M, N…etc. shells.

(B) Angular Momentum Quantum Number or Azimuthal Quantum Number (l)

- This quantum number is represented by the letter (l).
- It is used to describe sub-energy level.
- Values of azimuthal quantum numbers are all possible whole numbers from 0 to n-1

  When n=1 thus l=0 (Represents s-orbital)

  When n=2 thus l=0,1 (Represents s and p orbital)

  When n=3 thus l=0,1,2 (Represents s, p and d orbital)

  When n=4 thus l=0,1,2,3 (Represents s, p, d and f orbital)
- Thus various subshells are designated as s, p, d, f according to the value of l=0, 1, 2, 3 respectively.

(C) Magnetic Quantum Number (m)

- This quantum number is represented by the letter (m).
- It is used to describe the orientation of the orbitals.
- The number of values allowed to m depends on the values of l.
- Possible values of m range from –l through 0 to +l thus making a total of 2l+1 values. table 1.2

Table 1.2 : Magnetic Quantum Number

Azimuthal Quantum Number (l)	Calculation of Magnetic Quantum Number (m= 2l + 1)	Values of Magnetic Quantum Number	Orientation around the nucleus
l=0 (s-orbital)	m=2 x 0+1= 1	0	one
l=1 (p-obital)	m=2 x 1+1= 3	-1,0, +1	three
l=2 (d-orbital)	m=2 x 2+1= 5	-2, -1, 0, +1, +2	five
l=3 (f-orbital)	m=3 x 2+1= 7	-3, -2,-1,0,+1,+2,+3	seven

(D) Spin Quantum Number (m_s)

This quantum number is represented by (m_s).

It shows the direction in which the electron is spinning about its own axis.

The spin quantum number shows two possible values i.e. clockwise spin as $+\frac{1}{2}$ and anticlockwise spin as $-\frac{1}{2}$

1.1.8 Pauli's Exclusion Principle

No two electrons in a single atom can have same set of four quantum numbers.

In an atom two electrons can have a same set of three quantum numbers but they must differ in the value of fourth quantum number table 1.3

The first two electrons in [Ne] gas have the same set of three quantum numbers but differ in spin quantum number i.e. one with $+\frac{1}{2}$ spin and other with $-\frac{1}{2}$ spin.

Table 1.3 : Four Quantum Numbers for First 10 Electrons in [Ne]

Principal Quantum No. (n)	Azimuthal Quantum No. (l) = 0 to n-1	Magnetic Quantum No. (m)=-l to + l	Spin Quantum No. (ms)	Remarks
1 (K shell)	0 (s-sub energy level)	0	$+\frac{1}{2}$	First s electron in 1s
	0 (s- sub energy level)	0	$-\frac{1}{2}$	Second s electron in 1s
2 (L shell)	0 (s- sub energy level)	0	$+\frac{1}{2}$	First s electron in 2s
	0 (s- sub energy level)	0	$-\frac{1}{2}$	Second s electron in 2s

	1 (p- sub energy level)	-1	$+\frac{1}{2}$	First p electron in 2px
	1 (p- sub energy level)	0	$+\frac{1}{2}$	First p electron in 2py
	1 (p- sub energy level)	+1	$+\frac{1}{2}$	First p electron in 2pz
	1 (p- sub energy level)	-1	$-\frac{1}{2}$	Second p electron in 2px
	1 (p- sub energy level)	0	$-\frac{1}{2}$	Second p electron in 2py
	1 (p- sub energy level)	+1	$-\frac{1}{2}$	Second p electron in 2pz

1.1.9 Hund's Rule of Maximum Multiplicity

> When several orbitals with same energy are available, the electrons enters in all orbitals with parallel spin, before pairing in any one orbital.

Electron pairing in any orbital is not possible until the available orbitals of the same energy from the given subshell contains one electron each. Electrons of different atoms while entering into p-orbital follows Hund's rule as shown in table 1.4

Table 1.4 : Pairing Arrangement of Electrons Permitted by Hund's Rule

Description	**Orbital**	**Permitted by Hund's Rule**	**Not Permitted by Hund's Rule**
With one p electron e.g. B	p	[↑][ ][ ] px py pz	
With two p electrons e.g. C	p	[↑][↑][ ] px py pz	[↑↓][ ][ ] px py pz
With three p electrons e.g. N	p	[↑][↑][↑] px py pz	[↑↓][↑][ ] px py pz
With four p electrons e.g. O	p	[↑↓][↑][↑] px py pz	[↑↓][↑↓][ ] px py pz
With five p electrons e.g. F	p	[↑↓][↑↓][↑] px py pz	

With six p electrons e.g. Ne	p	↑↓ ↑↓ ↑↓ px py pz	

1.1.10 Aufbau Rule

When several orbitals are available, electron enters into all available orbitals with an increasing amount of energy. i.e. orbitals with lower energy are filled first then electrons enters into higher energy orbitals.

$1s<2s<2p<3s<3p<4s<3d<4p<5s<4d<5p<6s<4f<5d<6p<7s<5f<6d<7p<8s$

1.1.11 Electronic Configuration

Electronic configuration of $_3$Li can be written as follows

e.g.$_3$Li $1s^2$ $2s^1$

In case of lithium first two electrons enter into 1s orbital and after fulfilling the capacity of 1s orbital, the remaining electron enters into 2s orbital. Orbital electronic configuration of the first 11 elements are as shown in table 1.5

Table 1.5 : Orbital Electronic Configuration of Elements up to Atomic No. 11

Atomic Number	Symbol	Name of Element	Orbital Electronic Configuration			
			K	L	M	N
1	H	Hydrogen	$1s^1$			
2	He	Helium	$1s^2$			
3	Li	Lithium	$1s^2$	$2s^1$		
4	Be	Beryllium	$1s^2$	$2s^2$		
5	B	Boron	$1s^2$	$2s^22p^1$		
6	C	Carbon	$1s^2$	$2s^22p^2$		
7	N	Nitrogen	$1s^2$	$2s^22p^3$		
8	O	Oxygen	$1s^2$	$2s^22p^4$		
9	F	Fluorine	$1s^2$	$2s^22p^5$		
10	Ne	Neon	$1s^2$	$2s^22p^6$		
11	Na	Sodium	$1s^2$	$2s^22p^6$	3s1	

1.2 CHEMICAL BONDING

1.2.1 An Introduction

All matters are composed of atoms. Atoms do not exist in an isolated state in nature. All the naturally occurring elements such as gold, silver, diamond and naturally occurring compound such as water, sodium chloride, CO_2 always exists in combination only. Even the variety of compound being prepared synthetically are also having the atoms in a combined state.

Interesting fact : Water, sugar, oxygen, carbon dioxide, LPG, vinegar, nail polish remover, diamonds, table salt, washing soda, baking soda, Dettol, medicines etc. are all examples of compounds exist in combined state.

Fig. 1.8 : Importance of Chemical Compounds in Daily Life

A very important aspect about the compounds is that different elements have different combining capacity, as evident from the following example-

Table 1.6 : Combining Capacity of Different Elements

Different numbers of H atoms combining with single atoms of other elements	Different numbers of Cl atoms combining of other elements with single atoms
HCl	$NaCl$
H_2O	$CaCl_2$
NH_3	$AlCl_3$
CH_4	CCl_4

From the above example, it is evident that there is a certain relationship between the structure of atoms and the number of other combining atoms. The nature of the compound formed depends upon the valence electrons of the combining atoms.

Chemical bonding is the chemistry of a relationship that exists between the two atoms of the same or different elements. Let us understand the mystery of relationships in chemistry. This sub unit deals exclusively with different nature of relationships and characteristics of bonded atoms which are responsible for such nature of relationship in the form of different types of bonds.

> When two atoms tend to remain together rather than separate from each other, they are said to form a chemical bond with each other. A chemical bond may be defined as an attractive force which holds together the constituent atoms in a molecule.

The clue about chemical bonding came from a group of elements that show little tendency to form chemical compounds. In 1916, Lewis and Kossel found that inert gases do not combine with other elements, it means there is some peculiarity about their electronic configuration. Let us understand by Lewis theory.

(A) Lewis Octet Rule

According to the Lewis Octet rule, atoms of all elements tend to acquire an electronic configuration similar to that of inert gases because it represents the most stable electronic configuration. Valence electrons have a significant role in chemical bonding.

All the atoms with unstable or incomplete outer shell have a tendency to gain or lose electrons so as to acquire an electronic configuration of the nearest inert gas in the periodic table. This is called the **'Octet Rule'**

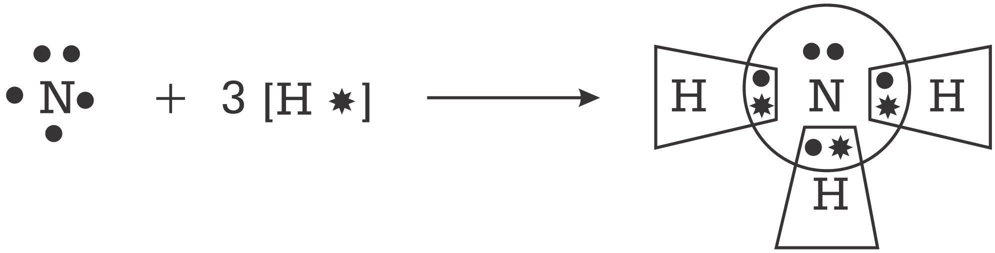


Fig. 1.9 : Lewis Structure of Ammonia

Legend : ○ and ⏢ Shapes are represented for understanding the concept of sharing only.

This tendency of atoms to complete and stabilize their outer most orbit of electrons is responsible for the chemical combination between the atoms. Octet can be made from some electrons which are totally owned and some electrons which are shared. Atoms continue to form bonds till they have made up an octet of electrons.

Example : In NH_3, Nitrogen atoms has 5 outer electrons. It shares three of these, forming three bonds and attain an Octet. Hydrogen has one electron and by sharing one electron, it attains a stable arrangement of two electrons [Fig. 1.9]

(B) Limitations of Octet Rule

Octet rule is helpful in understanding the structure of most of the organic compounds and second-period elements of the periodic table. There are certain exceptions to the octet rule as follows-

- The shape of the molecules cannot be explained by this.
- The relative stability and energy of a molecule cannot be explained by this.
- The octet rule is based on the chemical inertness of noble gases.
- Some noble gases like Xenon and Krypton combine with oxygen and fluorine to form the number of compounds.

1.2.2 Types of Bonds

Now let us understand the three ways, by which the atoms can acquire a stable electronic configuration by gaining, losing or sharing of electrons. Different types of bonds can also be understood in the following ways –

Table 1.7 : Types of Bonds

S.No.	Different types of Combination	Types of Bond
1.	Electropositive elements + Electronegative elements	Ionic bond
2.	Electronegative elements + Electronegative elements	Covalent bond
3.	Electropositive elements + Electropositive elements	Metallic bond

1.2.3 Ionic or Electrovalent Bond

(A) An Introduction

When a bond is formed by complete transference of electrons from one atom to another to complete their outermost orbit by acquiring eight electrons (i,e octet) or two electrons(i.e. duplet) e.g. in case of hydrogen, lithium and hence acquire the stable nearest noble gas configuration, the bond formed is called ionic bond or electrovalent bond.

> The chemical bond formed between two or more atoms as a result of the transfer of one or more electrons from electropositive to electronegative atoms is called electrovalent bond. This bond is also called ionic bond or polar bond

Ionic bonding results in the formation of two oppositely charged ions, positive ion (cations) and negative ions (anions), which results in a strong attractive force between them termed as ionic or electrovalent bond. Ionic bonds are formed between atoms with large differences in electronegativity. Ionic bond also possess some covalent character.

Formation of NaCl

The sodium chloride molecule contains one atom of sodium and one atom of chlorine.

Electronic configuration of atoms present in molecular formation are as

$_{11}Na$- $1s^2\ 2s^2\ 2p^6\ 3s^1$; (2, 8, 1)

$_{17}Cl$- $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$; (2, 8, 7)

$$\underset{\substack{2,8,1\\ \textit{Sodium atom}}}{_{11}Na} \longrightarrow \underset{\substack{2,\ 8\\ \textit{Sodium ion (Cation)}}}{_{11}Na^{+} + 1e^{-}}$$

Here sodium shows +1 positive electrovalency by loss of one electron and attains [Ne] gas electronic configuration

$$\underset{\text{2,8,7}}{_{17}\text{Cl}} + 1e^- \longrightarrow \underset{\text{2,8,8}}{_{17}\text{Cl}^-}$$

Chlorine atom *Chloride ion (Anion)*

Ionic Bonding

Here chlorine shows -1 negative electrovalency by the gain of one electron and attains [Ar] gas electronic configuration

Due to the loss and gain of one electron, ions are developed which held together by the electrostatic force of attraction. Due to the loss of one electron, sodium attains the nearest inert gas configuration of [$_{10}$Ne] gas while chlorine attains the nearest [$_{18}$Ar] gas configuration.

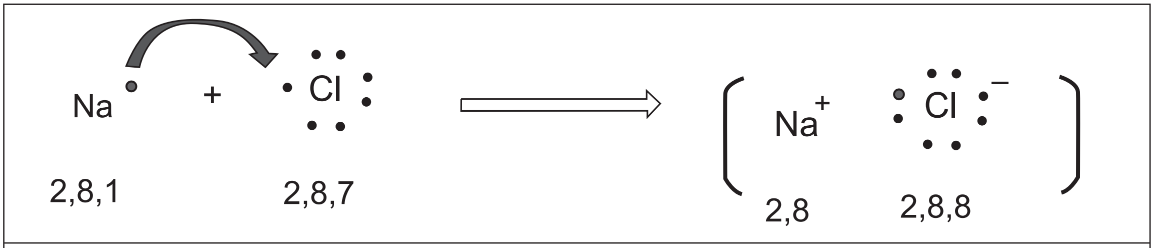


Fig. 1.10 : Electrovalent Bond /Ionic Bond Formation due to Transfer of Electrons

The bond which is formed by loss and gain of electrons or the bond which is formed by transfer of electrons is known as an electrovalent bond or ionic bond [Fig.1.10].

Generally metals are having 1,2,3 electrons in their valence shell, hence they have tendency to lose valence shell electrons and show positive electrovalency. Non-metals are having 5 or 6 or 7 electrons in their valence shell, hence they have tendency to accept electrons and show negative electrovalency.

When sodium and chlorine atoms are brought together, they are held together by the electrostatic force of their opposite charges and thus sodium chloride (Na^+Cl^-) is formed.

(B) Properties of Ionic Bond and Compounds

Some of the properties of Ionic bond & compounds are mentioned below-

- Ionic bonds are formed by the complete transfer of electrons from one atom to another.
- Atoms with higher electronegativity difference lead to the formation of an ionic bond. Ex- (NaCl)
- The ionic bond is formed between the metal and non-metal.
- Ionic bonds are non-directional and these compounds do not show isomerism.
- The ionic bond is weak.
- The ionic compounds are generally solids.
- Ionic compounds are made up of ions with powerful electrostatic forces of attraction
- Ionic compounds have generally high melting and boiling points due to strong electrostatic attraction between ions.
- Ionic compounds are generally soluble in polar solvents such as water and insoluble in organic solvents.

- Ionic compounds conduct electricity in the molten or dissolved state. In solid-state, they do not conduct electricity.
- Ionic compounds furnish ions in solutions, hence undergo ionic reactions which are very fast.
- Ionic compounds having similar electronic configuration exhibit the phenomena of isomorphism. For example, sodium fluoride and magnesium oxide show isomorphism.
- Ionic compounds, made up of positive and negative ions are arranged regularly in the lattice. These ions are held together by a strong electrostatic force of attraction known as Lattice energy.

SAQ-5	In which state, electrovalent compounds conduct electricity (Tick appropriately)		
	1. Fused	2. Solid	3. Gaseous

Key : 1

SAQ 6	Ionic Compounds show the property of			
	1. isomorphism	2. isomerism	3. polymorphism	4. polymerisation

Key : 1

SAQ 7	NaCl has maximum solubility in			
	1. ether	2. ethyl alcohol	3. acetone	4. water

Key : 4

1.2.4 Covalent Bond

(A) An Introduction

Langmuir refined the Lewis theory by introducing the term covalent bond. Lewis introduced simple symbols to denote the electrons present in the outer shell of an atom known as the valence electrons. These symbols are known as electron-dot symbols and the structure of the compound is known as Lewis dot structure. The dot represents the electrons. Such structures are known as Lewis dot structure. Lewis dot structures provide a picture of bonding in molecules and ions in terms of shared pair of electrons and the octet rule. Electron dot structures of covalent molecules are written with respect to octet rule.

According to this rule, all the atoms in the molecule will have eight electrons in their valence shell except the hydrogen atom. Hydrogen will have only two electrons because only two electrons complete its first shell to attain helium configuration.

Element of group 17, Cl will share one electron to attain a stable octet, the elements of group 16, O and S will share two electrons, the elements of group 15 will share three electrons and so on.

(B) Conditions for writing the Lewis dot structures

- Sharing of an electron pair between the atoms results in the formation of covalent bonds.
- Each bond consists of two electrons which are contributed by each one of the combining atoms during bond formation as shown in [Fig. 1.11]

- Each atom attains octet configuration in its valence shell by mutual sharing of electrons.

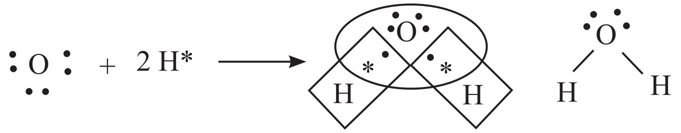


Fig. 1.11 : Lewis Dot Structure

The bond formed between the two atoms by mutual sharing of electrons between them so as to complete their octet or duplets (in case of elements having only one shell) is called covalent bond or covalent linkage and the number of electrons contributed by each atom is known as covalency. Each pair of shared electron is indicated by a line (-).

A covalent bond is formed by the equal sharing of electrons from both the participating atoms. The pair of electrons, which are participating in this type of bonding is called shared pair or bonding pair. Covalent bonds are also known as molecular bonds. By sharing bonding pairs, atoms achieve stability in their outer shell, similar to the atoms of noble gases.

(C) Covalent Bonding occurs in two ways

- Sharing of electrons between atoms of the same type e.g. Formation of H_2 [Fig. 1.12], Cl_2, O_2, etc.
- Sharing of electrons between atoms of different type e.g. Formation of CH_4, H_2O, NH_3, etc.

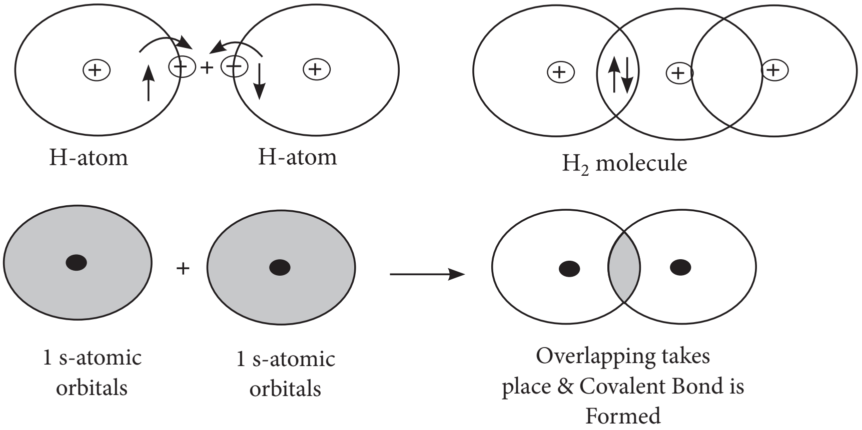


Fig. 1.12 : Formation of Hydrogen Molecule

Covalent Bonding

(D) Covalent Bond in C atom

The carbon atom has versatile nature. The carbon atom is able to form so many bonds with so many elements. Each C atom can either donate or accept four electrons to attain stable configuration. The atomic structure of carbon is 6. Its electronic configuration is 2, 4. Donating four electrons from the outermost orbit causes only two electrons left in it. In this case, the carbon atom will become positively charged but still remains unstable. Similarly accepting four electrons from outside will cause carbon atom to become negatively charged. In this situation also C atom remains unstable.

From the above explanation, it is inferred that, both the situation leads to the instability of carbon atom. Hence no option is left with C atom, but to share four electrons. Carbon cannot gain or donate electrons, so to complete its nearest noble gas configuration, hence carbon can share all the four valence electrons with other atom and thus forming covalent bonds.

(E) Types of Covalent Bond

Depending upon the number of shared electron pairs, the covalent bond can be classified into single, double and triple covalent bond. (table 1.8) and [Fig. 1.13]

Table 1.8 : Participation of Electrons in Covalent Bond Formation

Type of Covalent Bond	Name of Molecule as Example	No. of Mutually Shared Electron pair	*Bonding Electrons	**Lone pair of Electrons	Free Electrons
Single	Chlorine Cl_2	1	2	6	12
Double	Oxygen O_2	2	4	4	08
Triple	Nitrogen N_2	3	6	2	04

Legends

* Bonding electrons are those electrons which are taking part in bond formation.

** Lone pair of electrons are those which do not take part in bond formation.

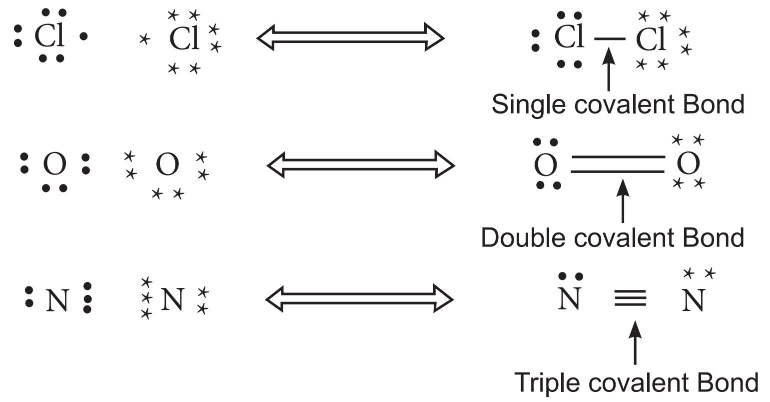


Fig. 1.13 : Types of Covalent Bond

(F) Properties of Covalent Bond and Compounds

Some of the properties of covalent bond & compounds are mentioned below-

- Covalent bonds are formed by sharing of electrons between the two atoms.
- The covalent bond is formed between two non-metals.
- Covalent bonds are rigid and directional.
- Covalent bonds are strong enough.

- If the electronegativities of the combining atoms do not differ much then the bond formed between them is likely to be covalent. e.g. Cl_2.
- A covalent bond normally contains energy of about ~80 kilocalories per mole (kcal/mol).
- Covalent compounds may be solids or liquids or gases.
- Covalent compounds are made up of molecules held together by weak Van der Waal's forces of attraction.
- Covalent compounds have normally low melting and boiling points.
- Covalent compounds are generally soluble in non-polar solvents such as benzene and insoluble in polar solvents such as water.
- Covalent compounds are generally bad conductors of electricity.
- These compounds show isomerism.
- Covalent compounds undergo molecular reactions which are very slow.

(F) Properties & Comparison of Electrovalent and Covalent Bond and Compounds

The concept and comparison of electrovalent and covalent bonding can be understood by the following [Fig. 1.14] and (table 1.9).

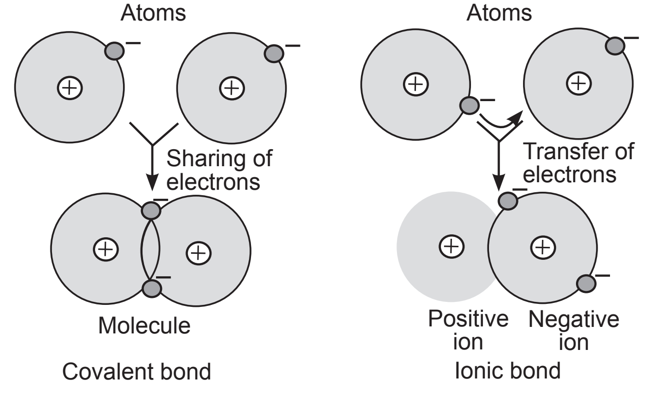


Fig. 1.14. : Comparison of Electrovalent and Covalent Bonding

Table 1.9 : Properties & Comparison of Electrovalent and Covalent Bonds &Compounds

Properties	Ionic Bond &Compounds	Covalent Bond & Compounds
Transfer/ sharing of electrons	These are formed by the complete transfer of electrons from one atom to another.	They are formed by sharing of electrons between the two atoms.
State of matter	These compounds are generally solids	These compounds may be solids or liquids or gases.
Bonding	These are made up of ions with powerful electrostatic forces of attraction between intermolecular species.	They are made up of molecules held together by weak van der waals forces of attraction.

Melting & boiling point	These have generally high melting and boiling points due to strong electrostatic force of attraction between ions	They have generally low melting and boiling points.
Solubility	Ionic compounds are generally soluble in polar solvents such as water and insoluble in organic solvents.	Covalent compounds are generally soluble in non-polar solvents such as benzene and insoluble in polar solvents such as water.
Conductor of electricity	Ionic compounds conduct electricity in the molten or dissolved state. In solid-state, they do not conduct electricity.	Covalent compounds are generally bad conductors of electricity.
Shape of molecule	Ionic bonds are non-directional and these compounds do not show isomerism.	Covalent bonds are rigid and directional. These compounds show isomerism.
Reactivity	These compounds furnish ions in solutions, hence undergo ionic reactions which are very fast.	These compounds undergo molecular reactions which are very slow.
Constituent of bond formation	The ionic bond is formed between the metal and non-metal	A covalent bond is formed between two non-metals
Strength of bond	The ionic bond is stronger	The covalent bond is weaker
Formation of bond w.r.t electronegativity difference	Atoms with higher electronegativity difference lead to the formation of an ionic bond. Ex-NaCl	If the electronegativities of the combining atoms do not differ much then the bond formed between them is likely to be covalent. e.g. Cl_2

SAQ 8	A Covalent bond is formed between			
	1. two non-metals	2.two metals	3. metal and non-metals	4. two ions

Key: 1

(G) Valence Bond Theory (VBT)

This theory was proposed by Linus Pauling. The covalent bond is formed by overlapping of valence shell atomic orbital (half- filled) of two different atoms having unpaired electrons. Because of overlapping, there is maximum electron density between the bonding atoms. The greater the overlapping of atomic orbitals, the higher is the strength of the chemical bond, thereby increasing the stability of the resulting molecule.

Features of the Valence Bond Theory

- The presence of many unpaired electrons in the valence shell of an atom enables it to form multiple bonds with other atoms. The paired electrons present in the valence shell do not take part in the formation of chemical bonds.

- Covalent chemical bonds are directional and are also parallel to the region corresponding to the atomic orbitals that are overlapping.
- Depending on the type of overlapping of atomic orbitals, sigma bonds (s) and pi bonds (π) are formed. pi bonds are formed from sidewise overlapping, whereas the overlapping along the axis containing the nuclei of the two atoms leads to the formation of sigma bonds.

Sigma Bond (σ)

When a covalent bond is formed by overlapping of half-filled atomic orbitals along the same axis it is called a sigma bond(s). Such type of bond is symmetrical about the line joining the two nuclei, as shown below. [Fig.1.15]. Examples of formation of H_2,F_2 and HF molecule are shown in [Fig. 1.16, 1.17 and 1.18].

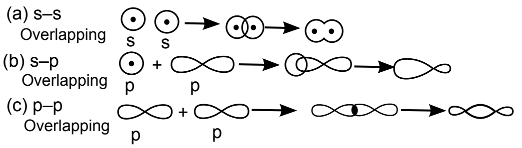


Fig. 1.15 : Orbital Overlap along the Axis

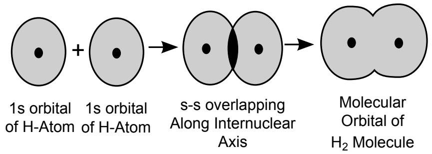


Fig. 1.16 : Formation of H_2 Molecule (s-s Overlapping)

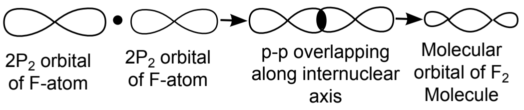


Fig.1.17 : Formation of F_2 Molecule (p-p Overlapping)

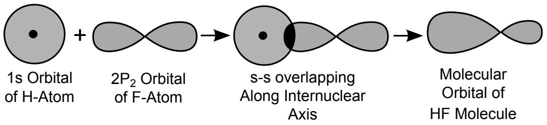


Fig.1.18 : Formation of HF Molecule (s-p Overlapping)

pi-Bond (π)

This type of bond is formed by sideways or lateral overlapping of two half- filled atomic orbitals. [Fig. 1.19]. The strength of a bond depends upon the extent of overlapping of half-filled atomic orbitals. The extent of overlapping is always greater when there is end to end overlapping of orbitals ,than when there is a sideways overlapping of orbitals. Sigma bond is always stronger than pi bonds between the two same groups of atoms.

The average distance between the nuclei of two bonded atoms in a molecule is called bond length and the energy required to break one mole of bonds of a particular type in the gaseous state is called bond energy or bond strength. The same amount of energy is released in the formation of 1 mole of a particular bond.

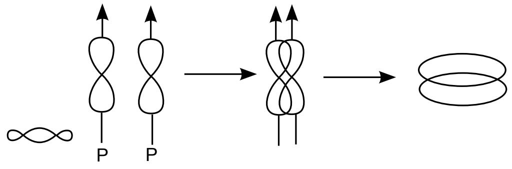


Fig. 1.19 : Orbital Overlap Sidewise

1.2.4 (H) Hybridisation

Hybridisation is hypothetical mixing of atomic orbitals belonging to same atom but having slightly different energies so that redistribution of energy takes place between them, resulting in the formation of new orbitals of equal energies and identical shapes. The new orbitals thus formed are known as hybrid orbitals The hybrid orbitals can be defined as the combination of standard atomic orbitals resulting in the formation of new atomic orbitals. In simple words, hybridisation may be defined as mixing and redistribution of atomic orbitals of more than one type to form new hybrid orbitals.

Important Features of Hybridisation are -

- Orbitals belonging to the same atom or ion having almost similar energies, get hybridized
- The number of hybrid orbitals formed are equal to the number of atomic orbitals taking part in hybridisation.
- Hybridisation takes place to produce equivalent orbitals which give maximum symmetry
- Hybrid orbitals form only a sigma bond.

Table 1.10 : Types of Hybridisation

Occupancy Bond pair + lone pair	Hybridisation	Bond Angle	Prototype Geometry	Orbitals % taking part in Hybridisatiton	Charact-eristics	Examples
Two	sp	180°	Linear	one s one p	s-50% p-50%	CO_2, $HgCl_2$, $BeCl_2$
Three	sp^2	120°	Triangular planar	one s two p	s-33.33% p-66.66 %	BF_3
Four	sp^3	109.5°	Tertrahedral	one s three p	s-25% p-75%	CH_4, BF_4

Formation of BF_3 Molecule

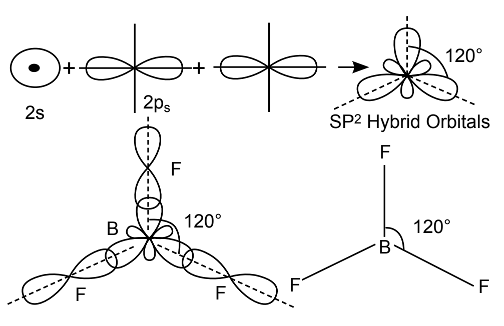


Fig. 1.20: Formation of sp^2 Hybrid Orbitals and Shape of BF_3Molecule

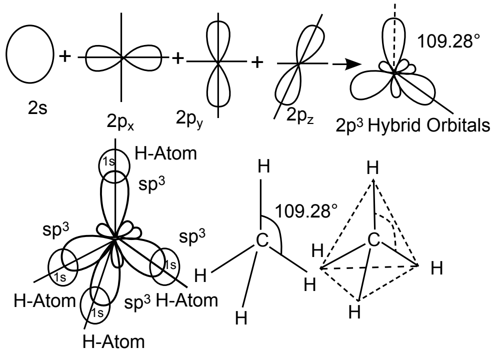


Fig. 1.21 : Formation of sp^3 Hybrid Orbitals and Shape of Methane (CH_4) Molecule

- The atomic number of Boron is 5
- Electronic configuration of B in the ground state is $1s^2\ 2s^2\ 2px^1$
- Electronic configuration of B in excited state is $1s^2\ 2s^1\ 2px^1\ 2py^1$

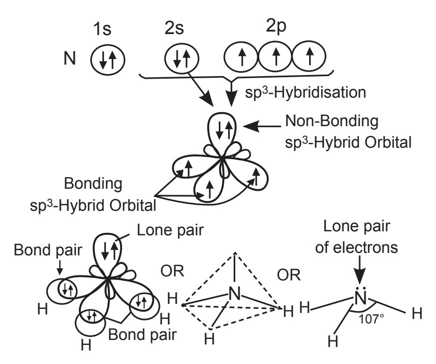
One 2s and two 2p orbitals undergo sp^2 hybridisation to form three half-filled sp2 hybrid orbitals which are planar and oriented at an angle of 120^0 to each other. These overlap with half-filled orbitals of three chlorine atoms to form BF_3 which is a triangular planar shape.[Fig.1.20]

Formation of CH_4 Molecule

- The atomic number of carbon is 6
- Electronic configuration in ground state is $1s^2\ 2s^2\ 2px^1\ 2py^1$
- Electronic configuration in excited state is $1s^2\ 2s^1\ 2px^1\ 2py^1\ 2pz^1$
- One 2s and three 2p orbitals undergo sp3 hybridisation to form four sp^3 hybrid orbitals which are arranged tetrahedrally at an angle of $109^0 28'$ to each other.
- The four sp^3 hybrid orbitals overlap with the half-filled 1s orbitals of 4 hydrogen atoms forming CH_4. CH_4 is a tetrahedral molecule with each H-C-H angle equal to $109^0\ 28'$ [Fig.1.21]

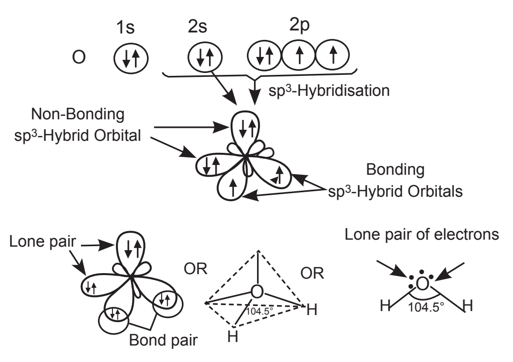
Formation of NH_3 Molecule

- The atomic number of Nitrogen is 7
- Electronic configuration in ground state is $1s^2\ 2s^2\ 2px^1\ 2py^1\ 2pz^1$
- One 2s and three 2p orbitals undergo sp^3 hybridisation to form four sp^3 hybrid orbitals which are arranged pyramidal at an H-N-H bond angle of 107^0.
- As lone pair –bond pair repulsion is greater than bond pair-bond pair repulsion hence although NH_3showing sp^3 hybridisation but bond angle get reduced from $109^0.28'$ to 107^0.
- The three sp^3 hybrid orbitals overlap with the half-filled 1s orbitals of 3 hydrogen atoms forming NH_3 as shown in in [Fig.1.22].



Formation of ammonia (NH_3) molecule.

Fig. 1.22 : sp^3 Hybridisation - NH_3



Formation of water (H_2O) molecule.

Fig. 1.23 : sp^3 Hybridisation-H_2O

Formation of H_2O molecule

- The atomic number of Oxygen is 8.
- Electronic configuration is $1s^2\ 2s^2\ 2px^2\ 2py^1\ 2pz^1$

- One 2s and three 2p orbitals undergo sp3 hybridisation to form four sp^3 hybrid orbitals which are arranged in 'V' shape
- The two sp^3 hybrid orbitals overlap with the half-filled 1s orbitals of 2 hydrogen atoms forming H_2O molecule which contains two lone pair and two bond pair of electrons.
- As repulsion between Lone pair - lone pair > lone pair - bond pair > bond pair - bond pair (L.P-L.P>L.P.-B.P.>B.P.-B.P.) hence although H_2O showing sp3 hybridisation but shows bond angle as $104^0 45'$ as shown in [Fig. 1.23].

Formation of $BeCl_2$ molecule

- The atomic number of Beryllium is 4.
- Electronic configuration is $1s^2\ 2s^2$ in ground state
- Electronic configuration in excited state $1s^2\ 2s^1\ 2px^1$
- One 2s and one 2px orbital mix to from two sp hybrid orbital
- 1s orbital of two hydrogen combines with two sp orbital of Be to form H-Be-H bond angle of 180^0 with linear geometry and sp hybridisation.

Molecular Orbital Theory

Characteristic of molecules their relative bond strength, paramagnetic and diamagnetic nature may be explained by another approach known as Molecular orbital theory. It says that when two atomic orbitals combine or overlap, they lose their identity and form new orbitals. The new orbitals formed are called molecular orbitals.

1.2.5 Coordinate Bond

(A) An Introduction

It is a special type of covalent bond in which both the shared electrons are contributed by one atom only. This bond is also called a dative Bond or dipolar bond.

They are formed in reactions that involve two non-metals such as a hydrogen atom or during bond formation between metals ions and ligands.(Ligand is an ion or molecule attached to a metal atom by coordinate bonding.) Co-ordinate covalent bonds can help in formation of complex organic molecules.

(B) Characteristic Features of Coordinate Bond

- The atom that shares an electron pair from itself is known as the donor. While the other atom which accepts these shared pair of electrons from the donor is known as a receptor or acceptor.

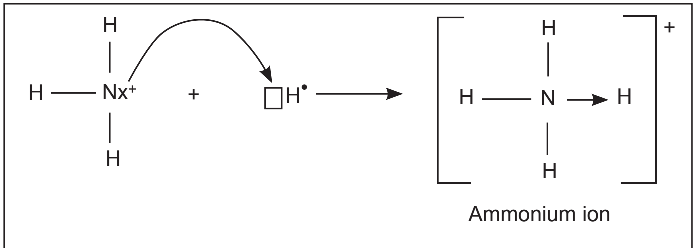


Fig. 1.24 : Co-ordinate Bonding in NH_4^+

- The bond is represented with an arrow → , pointing towards the acceptor from the donor atom. [Fig. 1.24].
- Each atom gets stability after sharing of electron pair.

(C) Properties of Coordinate Compounds

- Coordinate compounds have lower melting and boiling points than ionic compounds
- Some of these compounds exhibit isomerism.
- It is called a directional bond because sharing of electrons takes place in a definite direction.
- It is weaker than ionic bonding.

1.2.6 Hydrogen Bonding

Interesting fact: Hydrogen bonding has great significance in biological system. Water is present in plants and animals approximately 50% by weight. It is attached to the proteins by hydrogen bonding. Similarly, the structure of protein and nucleic acids are stabilized by hydrogen bonding.

When a molecule with hydrogen atom is linked to a highly electronegative atom (like F,O or N),the electronegative atom attracts the shared pair of electrons more and so this end of the molecule becomes slightly negative while the other end (i.e., H-end) becomes slightly positive. The negative end of one molecule attracts the positive end of the other, thus a weak hydrogen bond is formed between them. This bond is called Hydrogen bond .

It is represented by dotted lines(---)as shown here-

$$\overset{+\delta}{H}-\overset{-\delta}{X}----\overset{+\delta}{H}-\overset{-\delta}{X}-----\overset{+\delta}{H}-\overset{-\delta}{X}$$

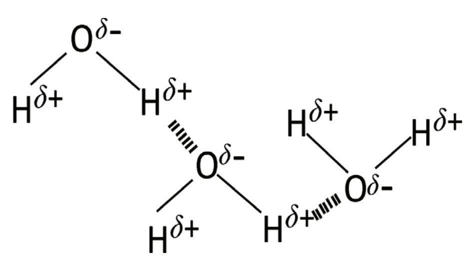


Fig. 1.25 : H Bonding in Water Molecule

Due to hydrogen bonding, an H-atom link with the two highly electronegative atoms simultaneously, one by a covalent bond and the other by a hydrogen bond. Thus it forms a Hydrogen bridge. For example, in water molecules (H_2O), hydrogen is covalently bonded to the more electronegative oxygen atom. The dipole-dipole interactions between the hydrogen atom of one water molecule and the oxygen atom of another H_2O molecule give rise to hydrogen bonding in water [Fig. 1.25]

The hydrogen bond is weak. The strength of the hydrogen bond is in-between the weak van der waals and the strong covalent bonds.

If we press two ice cubes over each other, they unite to form one cube due to hydrogen bonding.

(A) Conditions for Hydrogen Bonding

- The molecule must possess a highly electronegative atom linked to the hydrogen atom.
- The size of the electronegative atom needs to be small.

(B) Types of Hydrogen Bonding

Inter-Molecular Hydrogen Bonding : In this, two molecules of the same compound join to form aggregates. This type of bonding increases solubility in water and also the boiling point of the compound. [Fig.1.26].

Intramolecular Hydrogen Bonding : In this, hydrogen bonding occurs between atoms of the same molecules present on different sites. This leads to intramolecular ring formation and this phenomenon is called chelation.

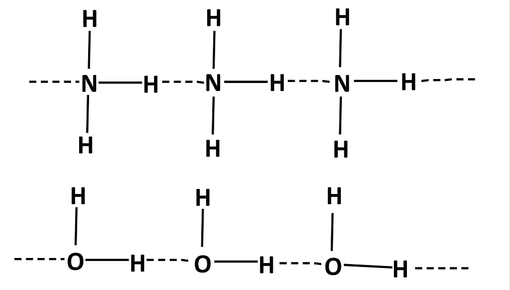


Fig. 1.26 : Intermolecular H Bonding

(C) Consequences of Hydrogen Bonding

- The compounds having hydrogen bonding show abnormally high melting and boiling point because extra energy is needed to break these bonds. The exceptionally high boiling point of hydrogen fluoride among the halogen acid is due to the presence of hydrogen bonding.
- High boiling and melting points of NH_3, H_2O and HI are due to hydrogen bonding
- Unique properties of water and ice are due to hydrogen bonding. The density of ice is less than water and water contracts when heated between 0^0C to 4^0C. These two unique properties are explained on account of the open cage structure of ice due to hydrogen bonding.
- The strength of certain acids and bases can be explained based on hydrogen bonding
- Organic compounds like alkanes, alkenes and alkynes are insoluble in water due to the absence of hydrogen bonding whereas alcohol, organic acids, amines are soluble in water due to hydrogen bonding.
- Water exists in a liquid state because hydrogen bonding exists in water. Whereas hydrogen sulphide exists in a gaseous state as no hydrogen bonding exists in hydrogen sulphide.
- The unusually high boiling point of hydrogen fluoride among the halogen acid is due to the existence of hydrogen bonding.

(D) Hydrogen Bonding in Water Molecule

- In water, each oxygen atom is linked to four H-atoms, two by covalent bonds & two by H-bonds. Each water molecule is linked to four water molecules tetrahedrally by H-bonds.
- Water has a maximum density at 277 K. At 273 K, there is sufficient hydrogen bonding present in the water molecules (or ice).
- Ice has a lower density than water. In the case of solid ice, the hydrogen bonding gives rise to a cage-like structure of water molecules, as each water molecule is linked to four water molecules tetrahedrally.
- When ice melts, this cage-like structure collapses and the molecules come closer to each other. Thus, for the same mass of water, the volume decreases and hence density increases. Therefore, ice has a lower density than water at 273 K. That is why ice floats on water.
- On heating, the hydrogen bonds start breaking and start coming together resulting in the decrease of volume and increase of density. This goes on up to 277 K. After 277 K, the increase in volume due to the expansion of liquid water becomes much more than the

decrease in volume due to the breaking of H bonding. After 277 K, there is a net increase of volume on heating, which means a decrease in density. Hence, the density of water is maximum at 277 K.

- Ice also has relatively high freezing and boiling point due to its hydrogen bonds. These are stronger than Vander Waals forces therefore more energy is needed to break the hydrogen bonds, resulting in higher freezing and boiling points.

Table 1.11 : Difference between Hydrogen Bond and Covalent Bond

Hydrogen Bond	Covalent Bond
The dipole-dipole intermolecular attraction between hydrogen atoms and an electro-negative atom leads to the formation of the Hydrogen bond.	It involves sharing of electrons between two atoms or molecules.
It is formed between a hydrogen atom and a highly electronegative atom such as F, O and N.	The covalent bond is formed between two electronegative atoms, belonging to the same element or of different elements.
The strength of this bond is very small. It changes the physical properties of bonding molecules. These are weak bonds	The bond strength of this bond is high. It changes the chemical properties of bonding molecules. These are strong bonds with greater bond energy

Anomalous properties of Water and Ammonia

- Water is a liquid whereas H_2S, H_2Se and H_2Te are all gases at ordinary temperature. In water, hydrogen bonding causes linkages in the water molecules which result in the boiling point of water than that of the other compounds.
- Because of strong intermolecular hydrogen bonding, H_2O, HF & NH_3 exist as associated molecules. Therefore, their melting and boiling point are much higher than those of the corresponding hydrides in their respective groups.
- Ammonia has a higher boiling point than PH_3 because there is hydrogen bonding in NH_3 but not in PH_3. Hydrogen bonding is responsible for ammonia's remarkably high solubility in water.

SAQ 9	The higher boiling point of water is attributed to			
	1. the covalent bond between H and O	2. linear shape of the water molecule	3. water molecules associate due to hydrogen bonding	4. water molecules are not linear

Key: 3

1.2.7 Metallic Bond

Giant structures of atoms are arranged in a regular pattern inside the metals. The electrons of the outer shells of the metal atoms are delocalised, and are free to move through the whole structure. This sharing of delocalised electrons results in strong metallic bonding. [Fig.1.27].

Collective sharing of a sea of valence electrons between several positively charged metal ions is known as Metal bonding. In other words, metallic bonding is the sharing of many detached electrons between many positive ions, where the electrons act as a "glue" giving the substance a definite structure.

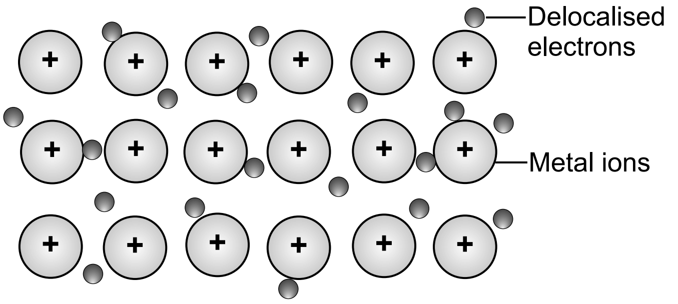


Fig. 1. 27 : Delocalised Electrons in Metallic Bond

Metallic bonds are loosened on heating causing the distortion in their definite, rigid structure and become liquid. These bonds are completely broken when the metal is heated to its boiling point.

Characteristic properties due to Metallic bonds

- High electrical and thermal conductivity
- Highly malleable and ductile
- Metallic lustre
- High melting and boiling points

Factors responsible for the Strength of Metallic Bonds

- If the number of delocalised electrons increases, the stronger will be the bond.
- If the magnitude of the charge on metal cation increases, the stronger the force of attraction between the electron sea and the cations.
- If the ionic radius of cation is smaller, the greater the effective nuclear charge acting on the electron sea.

Table 1.12 : Difference between Metallic Bond and Ionic Bond

Metallic Bond	Ionic Bond
Metallic bonds are formed when a rigid, definite lattice of metal cations share a sea of delocalized valence electrons.	It involves the transfer of electrons between two chemical species. They arise from a difference in the electro negativities of the bonded atoms.

SAQ 10	If two atoms share a single pair of an electron, the type of bonding is			
	1. Ionic	2. Single covalent	3. Double covalent	4. Triple covalent

Key : 2

SAQ 11	Chemical bonds are formed by			
	1. unstable atoms	2. stable atoms	3. neutral atoms	4. Noble atoms only

Key : 1

SAQ 12	Covalent bonds are formed by one of the following processes-	
	1. Complete transfer of one or more electrons from one atom to another	2. Sharing of electrons between the two combining atoms
	3. Shared electrons are contributed by one atom and not by each atom	4. Between the combining atoms

Key : 2

SAQ 13	The ionic bond is formed in one of the following molecules			
	1. NaCl	2. HCl	3. Cl_2	4. H_2O_2

Key : 1

SAQ 14	Metals lose electrons from their lattice to become			
	1. positive ions	2. Negative ions	3. Alkali	4. Non -metals

Key : 1

SAQ 15	Neither ions nor electrons are free to move in			
	1. liquid	2. metals	3. ionic solids	4. gases

Key : 3

SAQ 16	The conduction of electricity in metallic bond is due to the presence of			
	1. proton	2. lattice	3. delocalized electrons	4. nucleus

Key : 3

1.3 SOLUTION

1.3.1 An Introduction

For chemical analysis of different compounds and engineering materials and also for the preparation of many chemical compounds required in variety of industries, we need to comprehend in depth the preparation of solutions of different concentration. In this unit we shall be learning about preparation of solutions of different strength e.g. normal solution, molar solution, ppm solution etc.

Interesting fact : If you pour a handful of salt into a full glass of water, the water level will actually go down rather than overflowing the glass due to intermolecular bonding between ions.

1.3.2 The Idea of Solute, Solvent and Solution

For understanding the concept of solute, solvent and solution, let us consider the example of Sodium Chloride.NaCl salt is added into the water to form NaCl solution. In this case, we can call NaCl as a solute, water as the solvent and a mixture of salt and water as solution [Fig.1.28].

Now let us understand the definition of the three terms.

- **Solute :** Substance added to the solvent in small quantity is known as solute.
- **Solvent :** A substance present in a large quantity to dissolve solute, is known as a solvent.
- **Solution :** Homogeneous mixture of solute and solvent is known as a solution.

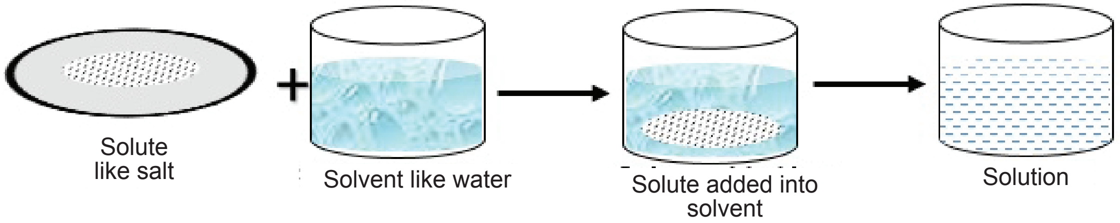


Fig. 1.28 : Solute-Solvent-Solution

1.3.3 Methods to Express the Concentration

The solution can be of varying concentration depends upon the amount of solute added to it.

Fig.1.29 : Concentration of Solution

Let us consider two solutions containing NaCl as a salt. Beaker 'A' contains 5.85 g of NaCl while beaker 'B' contains 58.5 g of NaCl. If we test this two beakers we can feel that the beaker 'B' is much more saltier as compared with beaker 'A'. In terms of concentration, we can say that solution in beaker 'B' is having a higher concentration of salt as compared with the solution in beaker 'A' [Fig.1.29]. There are various methods to express the concentration of the solution, some of them are as follows

(A) Molarity

Number of moles of solute dissolves in one litre of solution known as molar solution.

A solution in which 1 mole (equal to molecular weight) of compound solute is dissolved in the solvent and diluted up to 1000 ml thus we get 1 molar solution.

In the above example solution in beaker 'B' is a 1 molar NaCl solution (${}_{11}Na^{23}$ and ${}_{17}Cl^{35.5}$).

We can also calculate the number of moles of substance from given molarity as

$$\textbf{Molarity} = \frac{\text{Number of moles of solute}}{\text{The volume of solvent in L}}$$

Hence, Number of moles of solute=Molarity × Volume of solute

(B) Parts Per Million (ppm)

Parts per million is defined as the mass ratio of parts of solute to one million gram of sample ppm is a dimensionless quantity because it is a ratio of two quantities of the same unit.

$$\text{ppm} = \frac{\text{grams of solute}}{10^6 \text{grams of solution}}$$

It is also expressed as

Hardness in terms of $CaCO_3$

$$= \text{(strength of salt in mg/L)} \times \frac{\text{The Chemical Equivalent of } CaCO_3}{\text{Chemical Equivalent of Dissolved Salt}}$$

(C) Mass Percentage :

Percentage mass fraction of sample present in the entire mass

$$\text{Mass percentage solute} = \frac{\text{mass of solute}}{\text{mass of an entire sample}} \times 100\%$$

$$\text{Mass percentage sovent} = \frac{\text{mass of solvent}}{\text{mass of an entire sample}} \times 100\%$$

(D) Volume Percentage :

The percentage volume fraction of solute to the total volume of solution.

$$\text{Volume percentage} = \frac{\text{Volume of solute}}{\text{total volume of solution}} \times 100\%$$

(E) Mole Fraction :

Fraction of moles of solute or solvent to the moles of solution (i.e. moles of solute and moles of solvent)

$$\text{Mole fraction solute (or solvent)} = \frac{\text{Moles of solute (or solvent)}}{\text{moles of solution}}$$

SOLVED PROBLEMS

1.1 Write the orbital electronic configuration of an atom containing 12 Protons.

Sol. The Atom which is having 12 protons shows the same number of electrons hence the atom is of Mg having atomic no 12. The electronic configuration of Mg is as follows $_{12}Mg$ $1s^2$ $2s^2$ $2p^6$ $3s^2$

1.2 Write the orbital electronic configuration of an ion containing 12 protons & 10 electrons

Sol. The atom with 12 protons is of Mg.Electronic configuration of Mg atom containing 10 electrons. $_{12}Mg$ $1s^2$ $2s^2$ $2p^6$ $3s^0$

In this case, Mg lose its last shell or valence shell electrons for bond formation.

Hence now it becomes Mg^{2+} having 12 protons and 10 electrons.

1.3 Out of the two bonds Sigma and Pi, which one is stronger? Give reason.

Sol. Sigma bond is stronger because it is formed by head-on overlapping of atomic orbitals. In this case, the overlapping is also large. Whereas Pi bond is formed by sideways overlapping. Overlapping is small in this case.

1.4 There are two orbitals, one p and another sp hybrid orbitals. Out of these, which one has greater directional character, give reasons.

Sol. sp orbitals have greater directional character than p orbital because p orbital has equal size lobes with equal electron density in both the lobes. Whereas sp hybrid orbitals have greater electron density on one side.

1.5 H_2S is gas and water is liquid, Give reason.

Sol. Due to hydrogen bonding in water, there is an association of water molecules, but in H_2S there is no hydrogen bonding.

1.6 Boiling point of HF is higher than HCl, explain

Sol. Due to the presence of hydrogen bonding in HF, the molecules are associated together. While there is no hydrogen bonding in HCl.

1.7 Although Hydrochloric Acid is a covalent compound how it forms ions when dissolved into water.

Sol. Hydrochloric acid is covalent compound, which is formed my mutual sharing of one electron pair between hydrogen and chlorine. As chlorine is having 7 electrons in its valence shell hence having more tendency to attract shared pair of electrons towards itself called as electronegativity,hence formation of partial positive and negative charges over atom. When it is dissolved in water, permanent charges are developed over atoms hence due to more electronegativity of chlorine, HCl get ionised when dissolved in water

1.8 Explain the covalent character in CH_4.

Sol. Please refer to the section of Covalent bond in the text.

1.9 A solution of NaOH was prepared by dissolving 3.2 g of NaOH in 500mL in water. Calculate the molarity of NaOH solution (Hint : Refer point 1.3.3 (A))

Sol. Mass of NaOH 3.2g; Molar mass of NaOH = (23+16+01)=40g/mol

Volume of water 500 mL=500/1000 mL

Molarity =?

Molar mass $= \dfrac{\text{given mass}}{\text{molecular mass}} = 0.08$ mol

Molarity=(Number of moles of solute)/(the volume of solution in a litre)

$= \dfrac{\text{Number of moles of solute}}{\text{the volume of solution in a litre}} = (0.08 \times 1000)/500 = 0.16 \text{molL}^{-1}$ or 0.16 M

1.10 A water sample contains 400mg of Calcium sulphate per litre. Calculate the hardness in terms of $CaCO_3$ equivalent in mg/l, ppm(Hint : Refer point 1.3.3 (B)

Sol. The hardness of $CaSO_4$ in terms of $CaCO_3$

$= (\text{strength of calcium sulphate in mg/L}) \times \dfrac{\text{Chemical Equivalent of } CaCO_3}{\text{Chemical Equivalent of } CaSO_4}$

$= 400\text{gm} \times \dfrac{100}{136}$ [Equivalent Weight of $CaCO_3$=100, $CaSO_4$=136]=400 × 0.735 =294.11

As 1mg/L=1ppm therefore 294.11mg/L=294.11ppm

1.11 12 g of urea dissolved in 500g water. Calculate the percentage by mass of urea in the solution [Hint : Refer point 1.3.3 (C)]

Sol. Given Mass of Solute =12g; Mass of Solvent = 500g;

Mass of Solution = Mass of Solute + Mass of Solvent= 12+500=512 g

Mass Percentage Solute (Urea) = $\frac{\text{mass of solute (urea)}}{\text{mass of the entire sample (urea + water)}} \times 100 = \frac{12}{512} \times 100$
$= 0.023 \times 100 = 2.3\%$

1.12 15 cm³ of NaOH dissolved in 200 cm³ of water. Calculate volume percentage of NaOH. ([Hint : Refer point 1.3.3(D)]

Sol. Volume of Solute (NaOH)=15 cm^3 ; Volume of Solvent Water =200 cm^3;

Total Volume of Solution=215cm^3

Volume Percentage Solute = $\frac{\text{volume of solute}}{\text{total volume of solution}} \times 100\% = \frac{15}{215} \times 100 = 0.069 \times 100 = 6.9$

1.13 Calculate the mole fraction of solute and mole fraction of solvent in the sample of 100 g/ moles of water and 100 g/mole of ethyl alcohol (Hint : Refer point 1.3.3 (E))

Sol. Firstly we will change g of solute and solvent to moles

Moles of first substance = $\frac{100g}{18} = 5.55$

Moles of second substance = $\frac{100g}{46} = 2.17$

Hence mole of solution = 5.55 + 2.17 =7.72

Mole fraction of solute = $\frac{2.17g}{7.72} = 0.29$

Mole fraction of solvent = $\frac{5.55g}{7.72} = 0.71$

UNIT SUMMARY

- The fixed circular path in which electrons revolve around the nucleus is known as orbits or shells or energy levels and are represented as K, L, M, N…
- The maximum capacity of orbits to accommodate electrons is given by $2n^2$
- An atomic orbital thus represents the three-dimensional space around the nucleus where there is a maximum probability of finding an electron.
- The maximum capacity of orbitals to accommodate electrons in different orbitals is given by s=2, p=6, d=10, f=14
- The electron absorbs or emits energy in the form of photon or quanta (packet of energy). Emitted photons have different amount of energy hence produces spectral lines of different wavelengths.
- Heisenberg's uncertainty principle: It is not possible to determine precisely the exact position and momentum of a small moving particle simultaneously.
- Principal quantum number(n) give information about main energy level
- Azimuthal quantum number (l)provides information about sub energy level
- Magnetic quantum number (m) gives information of orientation of sub-energy level(m) (m= -l -0- +l for s=0, for p=-1, 0, +1, for d=-2, -1, 0, +1, +2 for f=-3, -2, -1, 0, +1, +2, +3).

- Spin quantum number (ms) gives the direction of spin(ms = +1/2 and -1/2)
- **Aufbau Rule :** Electron enters into all available orbitals with an increasing amount of energy.
- **Hund's rule of maximum multiplicity.** When several orbitals with same energy are available the electrons enters in all orbitals with parallel spin before pairing in any one orbital.
- **A chemical bond** may be defined as an attractive force that holds together the constituent atoms in a molecule.
- All the atoms with unstable or incomplete outer shell tend to gain or lose electrons to acquire an electronic configuration of the nearest inert gas in the periodic table. This tendency of atoms to complete and stabilize their outer most orbit of electrons is responsible for the chemical combination between the atoms.
- **Ionic or Electrovalent bond :** The chemical bond formed between two or more atoms as a result of the transfer of one or more electrons from electropositive to electronegative atoms is called an electrovalent bond. This bond is also called ionic bond or polar Bond or electrovalent bond
- **Covalent bond :** The bond formed between the two atoms by mutual sharing of electrons between them to complete their octet or duplets (in case of elements having only one shell) is called covalent bond or covalent linkage and the number of electrons contributed by each atom is known as covalency. Each pair of the shared electron is indicated by a line (-).
- **Coordinate Bond :** Coordinate Bond is a special type of covalent bond in which both the shared electrons are contributed by one atom only. This bond is also called a dative bond or dipolar bond. It is represented by arrow ($\rightarrow$).
- **Hydrogen Bonding :** In hydrogen bonding, an H-atom links with the two highly electronegative atoms simultaneously, one by a covalent bond and the other by a hydrogen bond. Thus it forms a Hydrogen bridge
- A covalent bond is formed by overlapping of valence shell atomic orbitals (half- filled) of two different atoms having unpaired electrons. Because of overlapping, there is maximum electron density between the bonding atoms. The greater the overlapping of atomic orbitals, the higher is the strength of the chemical bond, thereby increasing the stability of the resulting molecule.
- **Metallic bonding :** Collective sharing of a sea of valence electrons between several positively charged metal ions is known as Metal bonding. In other words, the metallic bond is the sharing of many detached electrons between many positive ions, where the electrons act as a "glue" giving the substance a definite structure
- **Solute :** Substance added to the solvent, in small quantity is known as solute.
- **Solvent :** A substance present in a large quantity to dissolve solute, is known as a solvent.
- **Solution :** Homogeneous mixture of solute and solvent is known as a solution.
- **Molarity :** Number of moles of solute dissolves in one liter of solution.
- **Parts per million (ppm) :** Parts per million is defined as mass ratio of parts of solute to one million gram of sample.

- **Mass Percentage :** Percentage mass fraction of sample present in the entire mass.
- **Volume Percentage :** Percentage volume fraction of solute to the total volume of solution.
- **Mole Fraction :** Fraction of moles of solute or solvent to the moles of solution (i.e. moles of solute and moles of solvent)

EXERCISES

1.1 State Heisenberg Uncertainty Principle.

1.2 Describe the appearance of hydrogen spectrum in different series appearing in different region.

1.3 Explain orbital concept with the shapes of s, p, d, f orbitals.

1.4 Explain the four quantum numbers in tabular form.

1.5 Write the sequence of orbitals in increasing amount of energy in Aufbau rule.

1.6 Write the orbital electronic configuration of $_{17}Cl$, $_{9}F$, $_{13}Al$, $_{15}P$.

1.7 Explain the formation of electrovalent bond in NaCl

1.8 Explain the formation of single, double and triple covalent bond with examples.

1.9 Differentiate between ionic compound and covalent compound on the basis of `transfer/ sharing of electrons, melting and boiling point and conductor of electricity.

1.10 Explain the formation of sigma and pi bond with s-s, p-p and s-p overlapping, with the help of neat diagram

1.11 Explain the hybridization in the formation of methane molecule.

1.12 State the properties of co-ordinate compounds.

1.13 Explain the anomalous behavior of water molecule.

1.14 Draw the diagram to explain the delocalized electrons in metallic bond. Mention characteristic properties of metallic bond.

1.15 Differentiate between solute, solvent and solution with the help of example.

1.16 Describe concentration of solution using the concept of i) Molarity ii) ppm and iii) Mole fraction

PRACTICALS

1. PREPARATION OF STANDARD SOLUTION

PRACTICAL STATEMENT

Prepare the standard solution of oxalic acid or potassium permanganate

PRACTICAL SIGNIFICANCE

Standard solutions are important for volumetric titrations and quantitative chemical analysis to determine an unknown concentration in a sample. Standard solutions are used by pharmacist in the medical word and in laboratory to get the proper mixture.

RELEVANT THEORY

NORMAL SOLUTION

The normal solution is prepared by dissolving 1 g equivalent weight of solute, making 1000mL of solution

Preparation of Normal Solution of Oxalic acid

Molecular weight of oxalic acid = 126.

$$\text{Equivalent weight} = \frac{\text{Molecular weight}}{\text{Basicity No}} = \frac{126}{2} = 63 \text{ (Valency of oxalic acid=2)}$$

1g equivalent weight of oxalic acid dissolved in 1000 mL distilled water, form 1N solution
63g of Oxalic Acid dissolved in 1000 mL distilled water, form, 1N Oxalic acid solution
0.63g of Oxalic acid dissolved in 1000mL distilled water, form, 0.01 N Oxalic acid solution

Preparation of 0.01N $KMnO_4$ solution

$$\text{Equivalent weight} = \frac{\text{Molecular weight}}{\text{Valency (Basicity No)}} = \frac{158}{5} = 31.6\text{g (Valency of } KMnO_4 = 5)$$

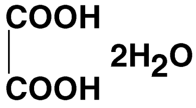
31.6 g of $KMnO_4$ dissolved in 1000mL distilled water to form 1 N $KMnO_4$ solution
0.316 g $KMnO_4$ dissolved in 1000 mL distilled water to form 0.01 N $KMnO_4$ solution

MOLAR SOLUTION

Number of moles of solute dissolved in 1000mL water,

Forms molar solution [For molar solution refer - Unit 1, section 1.3]

Preparation of 0.02 M Oxalic Acid Solution



$$\begin{array}{l} COOH \\ | \qquad 2H_2O \\ COOH \end{array}$$

Molecular formula of oxalic acid –($C_2H_6O_6$)
Molecular weight = [(2×12)+(6×1)+(6×16)]=[24 + 6 + 96]=126g/mol
Weight of Oxalic Acid = Molarity × Molecular Mass of Oxalic acid×Volume

$$= \frac{1}{50} \times 126 \times \frac{100}{1000}$$

Weight of oxalic acid = 0.252 g

For the preparation of 0.02 M oxalic acid solution, 0.252 g of oxalic acid is dissolved in 100mL water.

Preparation of Molar solution of Potassium Permanganate ($KMNO_4$)

Preparation of 0.02 M $KMnO_4$ solution
Molecular weight of $KMnO_4$ = [39+55+(16 × 4)] =158
Weight of $KMnO_4$ = Molarity × Molecular Weight of $KMnO_4$ × Volume

$$= \frac{1}{50} \times 158 \times \frac{100}{1000} = 0.316\text{g}$$

For Preparation of 0.02 M $KMnO_4$ Solution, 0.316g $KMnO_4$ is dissolved in 100 mL water

PRACTICAL OUTCOMES(PrOs)

PrO1 Weigh accurately the given sample in electronic balance.
PrO2 Prepare standard solution of given sample of defined molarity and normality.

RESOURCES, CHEMICALS AND GLASSWARE REQUIRED

- **Resources:** Electronic Digital/ Analytical Balance (0.0001 mg sensitivity)
- **Chemicals (AR Grade):** Oxalic acid, Potassium Permanganate
- **Glassware (Borosil):** Watch glass, Standard volumetric flask (100 mL), funnel, Beakers

SAFETY PRECAUTIONS

1. Use mask, gloves and apron while working in the lab.
2. Handle the glasswares and chemicals carefully
3. Never spill chemicals inside the balance.
4. Always add acid into the water for dilution.
5. For weighing chemicals, use watch glass. Use spatula for holding the chemical. Don't use bare hands for using chemicals.
6. Protect the prepared $KMnO_4$ solution from sun light. Cover it with aluminium foil or store in a dark bottle. Light accelerates the decomposition of $KMnO_4$

SUGGESTED PROCEDURE

Part-A Preparation of $\frac{M}{50}$ Oxalic Acid Solution

1. Clean the watch glass and weigh 0.252 g of oxalic acid, and transfer it into a standard volumetric flask and add distilled water up to 100mL mark.
2. Toggle the solution 3-4 times so that we can get a homogenous mixture of oxalic acid.

Part-B Preparation of $\frac{M}{50}$ $KMnO_4$ Solution

1. Clean the watch glass and weigh out 0.316 g of a gram of $KMnO_4$ and transfer it into a standard volumetric flask and add distilled water up to 100mL mark.
2. Toggle the solution 3-4 times so that we can get a homogenous mixture of $KMnO_4$.

Note for Teachers

Teacher can use any one method for the preparation of a standard solution of oxalic acid and $KMnO_4$ solution i.e. Molar solution method or Normal solution method.

OBSERVATIONS

Part - A Preparation of Oxalic Acid Solution

I) Preparation of…………….M oxalic Acid Solution

For the preparation of ……M oxalic acid, Weight of oxalic acid taken = ……………….
The volume of the used standard volumetric flask = ……………

II) Preparation of…………….. N oxalic acid solution

For the preparation of…………N oxalic acid, the weight of oxalic acid taken = …………

Part -B Preparation of $KMnO_4$

I) Preparation of……………..M $KMnO_4$ Solution

For the preparation of …………M $KMnO_4$, Weight of $KMnO_4$ taken = ……………

The volume of the used standard volumetric flask =……………..

II) Preparation of……………..N $KMnO_4$ solution

For the preparation of……….N $KMnO_4$, the weight of $KMnO_4$ taken = ……………

RESULT

………g of oxalic acid is used for the preparation of………….solution.

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

- Explain and write the preparation steps for the 0.02 M oxalic acid solution
- Explain and write the preparation steps for the 0.02 N $KMnO_4$ acid solution.
- Calculate amount of oxalic acid required for the preparation of 0.002 N oxalic acid.
- Calculate amount of $KMnO_4$ required for the preparation of 0.002 N $KMnO_4$

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.

2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

SUGGESTED LEARNING RESOURCES

1. https://vlab.amrita.edu/?sub=2&brch=193&sim=1548&cnt=1

Concentration of $KMnO_4$ solution

SUGGESTED ASSESSMENT SCHEME

Student's Name………..……………………....………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Accuracy in weighing of sample	10		Viva-voce	10		
Preparation of solution	30		Report preparation	10		
Housekeeping	10		Calculations, results and interpretation	10		
Handling of glasswares	10					
Observance/ follow safety precautions	10					

2. ACID-BASE TITRATION

PRACTICAL STATEMENT

Determine the strength of given sodium hydroxide solution by titrating against standard oxalic acid solution using phenolphthalein indicator.

PRACTICAL SIGNIFICANCE

An acid – base titration is used to determine the unknown concentration of an acid or base by neutralizing it with an acid or base of known concentration. Acid-base titrations find applications in pharmaceutical analysis in the determination of sodium chloride in glucose & sodium chloride injection.

RELEVANT THEORY

Acid base titration

Acid base titrations are based on the principles of acidimetry and alkalimetry. The chemical reaction involved in acid-base titration is known as neutralisation reaction. It involves the combination of H_3O^+ ions with OH^- ions to form water. In acid-base titrations, solutions of alkali are titrated against standard acid solutions. The estimation of an alkali solution using a standard acid solution is called acidimetry. Similarly, the estimation of an acid solution using a standard alkali solution is called alkalimetry.

Titration

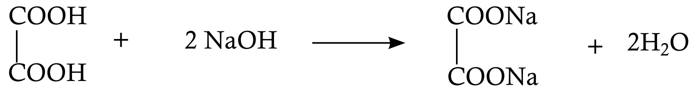
The standard solution is usually added from a graduated vessel called a burette. The process of adding standard solution until the reaction is just complete is termed as titration and the substance to be determined is said to be titrated.

Indicator

It is a chemical reagent used to recognize the attainment of end point in a titration. After the reaction between the substance and the standard solution is complete, the indicator should give a clear colour change.

End point and Equivalent point :

For a reaction, a stage which shows the completion of a particular reaction is known as end point. Equivalence point is a stage in which the amount of reagent added is exactly and stoichiometrically equivalent to the amount of the reacting substance in the titrated solution. The end point is detected by some physical change produced by the solution, by itself or more usually by the addition of an auxiliary reagent known as an 'indicator'. The end point and the equivalence point may not be identical. End point is usually detected only after adding a slight excess of the titrant. In many cases, the difference between these two will fall within the experimental error. The reaction applicable in this practical is



$$\begin{matrix}\mathrm{COOH}\\ |\\ \mathrm{COOH}\end{matrix} + 2\,\mathrm{NaOH} \longrightarrow \begin{matrix}\mathrm{COONa}\\ |\\ \mathrm{COONa}\end{matrix} + 2H_2O$$

Oxalic Acid   Sodium Hydroxide   Sodium Oxalate   Water

PRACTICAL OUTCOMES (PrOs)

- PrO1 Identify the difference between an "endpoint" and an "equivalence point" in an acid-base titration.
- PrO2 Weigh accurately the given sample in electronic balance
- PrO3 Prepare sample solution
- PrO4 Calculate the strength of the given acid or base using molarity equation.

CHEMICALS AND GLASSWARE REQUIRED

- **Chemicals (AR Grade):** Oxalic acid, sodium hydroxide, phenolphthalein
- **Glasswares (Borosil):** Beaker (250mL and 100mL), conical flask (100mL), burette (50mL), burette stand, pipette (10mL)

SAFETY PRECAUTIONS

1. Rinse and fill NaOH solution in the burette.
2. Remove the air gap present in the nozzle of the burette.
3. Fill the NaOH solution in the burette such that the lower meniscus should be at zero.
4. Use mask, gloves and apron while working in lab.

SUGGESTED PROCEDURE

1. Prepare 0.1 N NaOH solution
   (40g of NaOH dissolved in 1000mL distilled water to form 1M NaOH solution
   4.0 g of NaOH dissolved in 1000mL distilled water to form 0.1M NaOH solution
   [For Preparation of oxalic acid refer –applied chemistry lab Practical 1 section 1.3
2. Rinse and fill given sodium hydroxide in clean burette upto zero mark.
3. Pipette out 20mL of oxalic acid and transfer it into the conical flask
4. Add 2-3 drops of phenolphthalein indicator into the conical flask.
5. Add dropwise NaOH from burette into the conical flask and stir the mixture.
6. Repeat the step (4) until colour changes from colourless to permanent light pink. i.e. at the endpoint of titration.
7. After the formation of permanent light pink colour stop the addition and record the burette reading.
8. Repeat procedure for three consecutive readings.

OBSERVATIONS AND CALCULATIONS

1. The solution in burette ……………………........
2. Solution by pipette……………………………
3. Indicator used …………………………….…
4. End point ……………………..………………

Observation Table

Burette Readings	Pilot Reading	1	2	3	Volume of Base (VB) = Mean Difference = (1+2+ 3) / 3
Initial Burette Reading (IBR)					
Final Burette Reading (FBR)					
Difference (FBR-IBR)					

Calculations

Molarity of NaOH

NaOH vs Oxalic Acid

Molarity of Base (MB) x Volume of Base(VB) = Molarity of Acid(MA) x Volume of Acid (VA)

Molarity of NaOH = $M_B = \frac{M_A \times V_A}{V_B} = \frac{0.1 \times 20}{\text{From observation table } (V_B)}$ = …………………. M

Strength of NaOH = Molarity of NaOH× Equivalent Weight of NaOH

= ……………… × 40 g/L = ……………… g/L

RESULTS AND/OR INTERPRETATION

1. Molarity of NaOH = ……………..M
2. Strength of NaOH = ……………g/L

CONCLUSIONS AND/OR VALIDATION

………… amount of NaOH dissolve for the preparation of ………………… M solution

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Explain the role of the phenolphthalein indicator.
2. Explain and write the acid base neutralization reaction.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin) ♻	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

4. Unused solutions remained in the burette and beakers must be stored separately in conical flask for further use.

SUGGESTED ASSESSMENT SCHEME

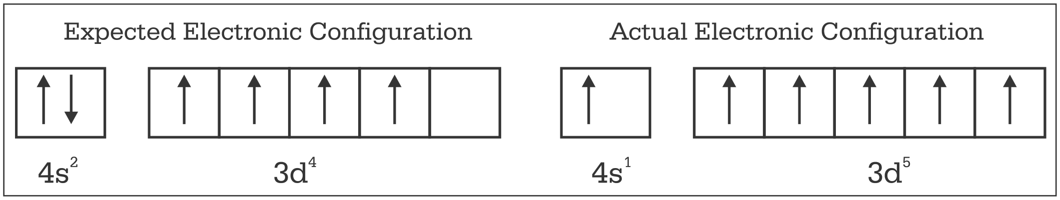
Student'sName……………………..........……………………RollNo……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Accuracy in preparation of solution	15		Viva-voce	10		
Titration process and identification of endpoint	20		Calculations, Results & interpretation	10		
Housekeeping	10		Report preparation	10		
Handling of glasswares	15					
Observance/ follow safety rules	10					

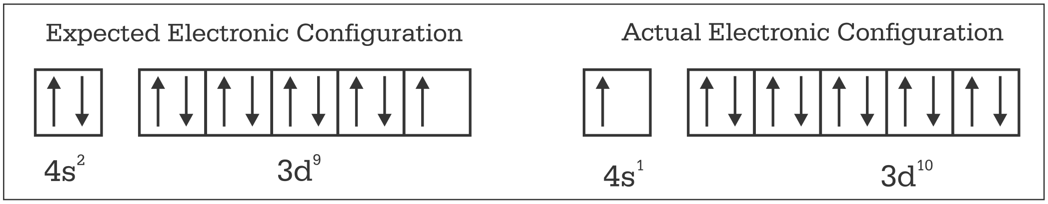
KNOW MORE

- **Atomic number :** Atomic number is the number of protons present inside the nucleus. It is represented as (Z)
- **Atomic Mass number :** Sum of the number of proton and number of neutrons present inside the nucleus. It is represented as 'A'. A= P+N.
- **Atomicity :** Number of atoms present in the molecule of an element. The atomicity of the Hydrogen molecule is 2. Atomicity of Nitrogen, oxygen (in Oxygen gas) =2
- **Isotopes :** Different atoms of the same element with same atomic number but the different atomic mass number is called as isotopes 1H1, 1H2, 1H3
- **Isobars :** Different atoms of different elements with different atomic number but having the same atomic mass numbers are called isobars. 18Ar40, 19K40, 20Ca40
- **Lone pair of electrons :** A pair of electrons that do not take part in the bond formation are known as lone pair of electrons
- **Bond pair of electrons :** A pair of electrons that take part in the bond formation between two atoms are known as bond pair of electrons

- Chromium shows exceptional electronic configuration.
- Instead of showing $4s^2$ $3d^4$ valence shell electronic configuration, it shows $4s^1$ $3d^5$ configuration due to half-filled d orbitals are relatively more stable.



- Copper shows exceptional electronic configuration. Instead of showing $4s^2$ $3d^9$ valence shell electronic configuration, it shows $4s^1$ $3d^{10}$ configuration due to completely full-filled d orbitals are relatively more stable.



Suggested Micro projects / activities

- Prepare a PowerPoint animation that can explain the structure of an atom.
- Prepare a chart of the modern periodic table which gives information about the atomic number and mass number of different elements.
- Prepare common salt crystals from NaCl solution
- Prepare a chart representing compounds and solutions which affects human life positively and negatively.
- Prepare a model of an atom with the help of a ball and stick or of any other items.
- Form three groups of students in the class. Consider a hypothetical situation of exchanging/ sharing/giving of different items/belongings and demonstrate the type of ionic, covalent and co-ordinate bonding amongst the students in a simulated situation. Present your findings.
- Over the period, you might have undergone different experiences with your colleagues while playing outdoor games like cricket, football, hockey etc. Write or share, the narration of experiences in the form of story/case, analogous to different types of bondings.

Applications (Real Life / Industrial)

- All substances/compounds being used by all of us for domestic and industrial purposes are result of Chemical bonding. Chemical bonding had caused the scientists to design and create variety of new engineering materials and formation of chemical compounds with desirable properties for specific uses for the purpose of use in variety of applications in spectrum of different domain of industries such as cosmetics, polymers, steel, food, infrastructure etc.
- With the help of molarity, we can calculate pH of a solution using the formula of $pH= -\log10[H+]$

Case study of Ionic bonding, Covalent bonding and Co-ordinate bonding

Part 1

Suraj and Gopal were two very good friends. They both were studying in class 12th in Saraswati Vidya Mandir. This school is known for its activity-based teaching-learning using ICT tools and systems in place. Over the years, alumni of this school had been demonstrating their exemplary performance in many fields during their job. Suraj and Gopal were fairly good in their studies. Suraj was belonging to a well-off family and Gopal was from a poor family. Gopal's father was working as labour. He could support the studies of Gopal with only bare minimum facilities. They used to sit in different benches in the class, based on their heights, as Gopal was very tall.

Suraj was in habit of studying with online resources, such as e-books, open web resources, class notes, discussion Forum and other informal avenues. Gopal's father asked him to discontinue the studies because of the very bad financial condition of his family due to the pandemic Corona, as he could not work and get the daily wages due to the national lockdown. Gopal could realise the condition of his family and was too much disturbed thinking about his career. He shared all this with Suraj. Listening to all this, Suraj felt very bad about Gopal and could not sleep in the night .In the morning, Suraj shared his feeling with his father and requested him to purchase a set of books and stationery for his friend Gopal .His father readily agreed for the same. Suraj provided Gopal all the necessary things needed for the studies i,e books , stationery, notebooks etc including the exam fee.

Gopal was very happy and emotional to learn this, as because of full support of his friend Suraj, he could continue his studies. He was overwhelmed and grateful to Suraj for the same.

Part 2

Suraj and Gopal both continued to study happily and performed well in the class. They used to often share their personal notes and class notes. Even for difficult concepts, they used to do joint study. As per the policy of the institute, science teacher used to give certain assignments/ projects to the students in groups to learn better through activities and micro-projects. Suraj and Gopal used to create very good original projects jointly by utilising the waste material around and exploring the required things and good materials from city Kabada market. Even during the science exhibition competition at the state level, their project was awarded at the state level and they got an appreciation of their joint efforts in developing the original project.

Part 3

At a later stage, after a half-yearly examination, Gopal developed the disability of hearing due to a fungal infection in his ear. He was too perturbed as he could not hear and grasp any instructions which were being given during practical and theory classes by the teachers. It was becoming very difficult for Gopal to perform in the class.

Suraj requested the teacher that he wants to sit with Suraj on the same bench to help him out in his studies, as he cannot hear the important valuable instructions imparted by you. The teacher immediately agreed to the same. Now Suraj and Gopal started sitting on the same bench and Suraj used to communicate every single instruction to Gopal through written and nonverbal communication. By this, he could transfer all learning & instructions during theory and practical classes to Gopal.

After the examination, both performed very well and got selected in very good colleges of their choices.

Points for discussions

- Relate and explain the narration of the case with the concept of chemical bonding
- Identify and relate the three parts of the case with ionic, covalent and co-ordinate bonding.
- Present the findings of above points and discuss with the tutor to further clarify the concepts.

Note for Teachers

All Students in the class may be divided into many groups of 10 each. Each group will have a leader and rapporteur. Each group may be asked to read, comprehend & discuss the case within the group in stipulated time and present the findings based on the points given below. The teacher may interact and provide feedback and summarise at the end.

Inquisitiveness and Curiosity

- Why noble gases do not interact with other elements.
- Although Hydrochloric Acid is a covalent compound, how it forms ions when dissolved into water?
- Chemical bonding is being learnt since many years. We have learnt that the synthesis of medicines is the result of chemical bonding. There is an urgent need to synthesize relevant medicines by the scientists, chemist and pharmacist as per pandemic situation and also for many fatal diseases. In past there were many casualties due to pandemic. We could have prepared sufficient doses of medicines and vaccines for each individual of all age groups in our nation, at the early stage of pandemic only to avoid such situation.
- Can a rhythmic song or acronym be developed for remembering the elements atleast from atomic number 1 to 30.
- How do we know and believe that all things in the universe are made up of atoms? It is analogous to the belief in the existence of God. How can we see and feel the existence of an atom? Everything looks theoretical.
- When equal volumes of water and ethyl alcohol are mixed, the total volume is less than that of the two liquids before mixing.

REFERENCES AND SUGGESTED READINGS

- C. N. R. Rao, Understanding Chemistry, Universities Press (India) Pvt. Ltd., 2011, ISBN 8173712506
- Shikha Agarwal, Engineering Chemistry, Cambridge University Press; New Delhi, 2015. ISBN, 978-1-107-47641-7
- Dara, S. S. & Dr. S. S. Umare, Engineering Chemistry, Universities Press (India) Pvt.Ltd., 2011, ISBN, 8121903599
- Jain & Jain, Engineering Chemistry, Dhanpat Rai and Sons; New Delhi, 2015, ISBN 8187433175
- Text Book of Chemistry for Class XI & XII (Part-I,Part-II), N.C.E.R.T., Delhi, 2017-18.
- Chemsketch and ISISdraw which can be used to understand 3D view of an orbital.

2

Water

UNIT SPECIFICS

This unit comprises of the following major topics :

- Water its distribution on earth and classification
- Causes of hard water
- Water softening techniques
- Municipal water treatment
- Indian standard specification of drinking water
- Water for human consumption for drinking and cooking purposes from any water sources

The different concepts have been explained through examples for generating further curiosity and inquisitiveness and also developing creative problem solving abilities in the students, with the mention of their practical applications in the industries/day to day life.

Assessment for learning at different intervals within the unit, at different levels of cognitive domain is carried out by designing formative assessment questions.

For effective implementation of the outcome based curriculum in true spirit, wide spectrum of activities such as micro projects, assignments, industrial visits etc, are designed and integrated in the unit for the benefit and exposure of the students. Sample QR codes have been provided on various topics/sub topics for supplementary reading and reinforcing the learning.

RATIONALE

Water is a precious natural resource. All living things need water for their survival. We cannot imagine life without water. Let it be animals or plants they require water to complete their daily metabolic activities. Plants require water to synthesise their food from the process of photosynthesis. Water on earth is cycled continuously through evaporation, transpiration, condensation, precipitation and other means.

Sustainable development goal target 6.1 calls for universal and equitable access to safe and affordable drinking water.

Industrial wastewater coming out from industries (tanneries, laundries, pickles etc.) is full of chemical compounds with different concentrations. This wastewater from industries is being released in the lake, river or sea and affects the quality and purity of water and also affect the ecosystem. It can cause a phenomenon called eutrophication. It can cause fish and other aquatic organisms to die. Toxic elements dissolved in water can make their way to humans through fish or other marine organisms.

Being the diploma engineer, it's our responsibility to use the available water judiciously for long term sustainability and spread awareness about using safe and clean drinking water. We should celebrate the World Water Day on 22nd March with the determination that we will conserve, preserve and judiciously use the available water.

Interesting fact: 90% of all natural disaster are water related (UNISDR)

PRE-REQUISITES

Chemistry	:	Composition of matter
Mathematics	:	Basic algebra and geometry

UNIT OUTCOMES

List of outcomes of this unit are as follows :

U2 – O1	Classify hard and soft water based on their properties.
U2 – O2	Determine the hardness of water by EDTA method.
U2 – O3	Soften the hard water by applying the different water softening techniques.
U2 – O4	Apply the different water treatment methods for purification of water.
U2 – O5	Use the Indian standard specification of drinking water.

Unit - 2 Outcomes	Expected Mapping of Unit Outcomes with the Course Outcomes (1- Weak Correlation; 2- Medium Correlation; 3- Strong Correlation)				
	CO-1	CO-2	CO-3	CO-4	CO-5
U2-O1	-	3	-	-	-
U2-O2	1	3	-	-	-
U2-O3	-	3	-	-	-
U2-O4	-	3	-	-	-
U2-O5	-	3			

2.1 An Introduction

Water is everywhere on the earth, i.e. above the earth, in the air, in the clouds, on the earth's surface in the form of rivers, oceans, ice, plants, and living organisms.

Water is extremely crucial for the proper functioning of the human body. Infact, about 60 percent of the human body is made up of water while blood consists of 90 percent water. Water lubricates the joints, forms an integral part of saliva and mucus and most importantly carries oxygen to different parts of the body through the blood. It also provides a cushion for the brain, spinal cord, and other sensitive tissues, keeps the skin healthy, regulates body temperature, helps in digestion, flushes out waste, maintains functioning of the kidneys, helps maintain blood pressure, and dissolves vital minerals and nutrients in the body.

In this unit, we will learn about different aspects of water

Interesting fact : Seawater is an impure form of water. It contains about 3.5% total dissolved salts. Dissolved salts of seawater contain about 2.5% of NaCl

2.1.1 Graphical Representation of Water Distribution on the Earth

Different pie charts are helpful to understand the existence and distribution of available water on the earth. Fig. 2.1 represents a pie chart of earth water. Out of total existing water,only 3% of water is freshwater, while the remaining 97% of water is saline or seawater. Fig. 2.2, shows the percentage distribution of freshwater. Almost 99% of it is locked up in ice and the ground; only a slight 1% of all is surface water. Fig. 2.3 shows the breakdown of surface freshwater. 69% of this water is locked up in ice, and another 21% is found in lakes. Soil moisture contains 3.8% water, the atmosphere contains 3% water and swamp and marshes have 2.6% water. Rivers account for a small percentage of fresh water i.e. 0.49%, large portion of which is available for living organisms.

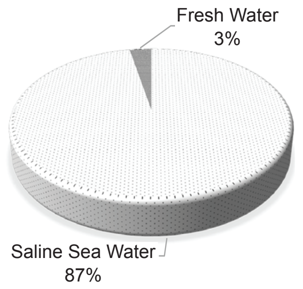


Fig.2.1 Earths Water

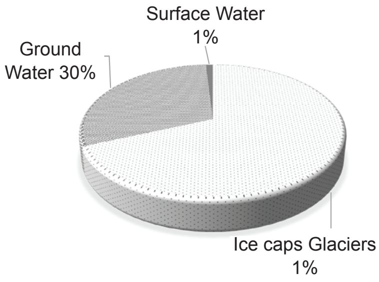


Fig. 2.2 Fresh Water

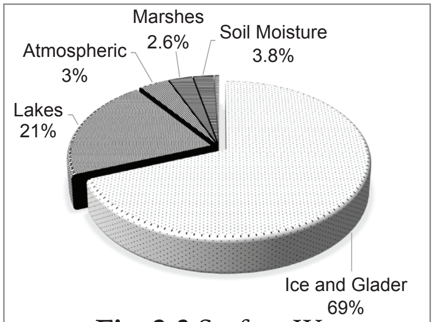


Fig. 2.3 Surface Water

2.1.2 Classification of Soft and Hard Water

(a) Soft Water

Water that produces lather easily on shaking with soap solution is called **soft water.**

Soap is sodium or potassium salt of higher fatty acids. When soap is mixed with soft water,the lather is produced due to stearic acid and sodium stearate.

$$\underset{\text{Sodium Stearate (Soap)}}{C_{17}H_{35}COONa} + H_2O \longrightarrow \underset{\text{Stearic Acid}}{C_{17}H_{35}COOH} + NaOH$$

$$\underset{\text{Soap}}{C_{17}H_{35}COONa} + \underset{\text{Stearic Acid}}{C_{17}H_{35}COOH} \longrightarrow \text{Lather}$$

(b) Hard Water

Water that does not produce lather with soap solution readily, but forms a white curd i.e. white scum is called **hard water.**

Soap is a mixture of sodium or potassium salt of higher fatty acids. Soap is soluble in water and forms salty end and fatty end, which helps cleanse action. When water combines with soap, it creates lather, due to which it has cleansing property. When water containing dissolved salts like magnesium and calcium is mixed with soap, insoluble salts of magnesium and calcium salts are obtained.

2.1.3 Salt Causing Water Hardness

Natural water is usually contaminated by different types of impurities i.e. dissolved, suspended and biological which might restrict its usefulness.

The hardness of water is mainly due to the presence of different salts in a dissolved state. Hardness is basically of two types

A) Temporary Hardness B) Permanent Hardness

(A) Temporary Hardness

Hardness of water which can be removed by mere boiling is known as **temporary hardness.**

Temporary Hardness

Such hardness is caused by the presence of dissolved bicarbonates of magnesium, calcium and other metals. In this type of hardness, soluble salts of metal, bicarbonates are decomposed, yielding insoluble carbonates or hydroxides after heating.

$$\underset{\text{Calcium Bicarbonates}}{Ca(HCO_3)_2} \xrightarrow{\Delta} \underset{\text{Calcium Carbonates}}{CaCO_3\downarrow} + H_2O + \underset{\text{Carbon Dioxide}}{CO_2\uparrow}$$

$$\underset{\text{Magnesium Bicarbonates}}{Mg(HCO_3)_2} \xrightarrow{\Delta} \underset{\text{Magnesium Hydroxide}}{Mg(OH)_2\downarrow} + \underset{\text{Carbon Dioxide}}{2\,CO_2\uparrow}$$

(B) Permanent Hardness

A hardness that cannot be removed by mere boiling is known as **permanent hardness.**

Permanent Hardness

Such hardness is caused by chlorides, sulphides of magnesium, calcium and other heavy metals. In this type of hardness, dissolved chlorides, sulphates are not decomposed after boiling.

Table 2.1 Difference between Soft Water and Hard Water

Soft Water	Hard Water
It contains less mineral content	It contains high mineral content
Contain Sodium ion	Contain Calcium and Magnesium ions
Soap is not wasted	A large quantity of soap is wasted
React with soap to form lather	React with soap to form precipitate scum or curd
Does not have an ill effect on domestic and industrial use	It affects domestic as well as industrial life.
In the paper industry, high-quality paper produced having desired smoothness and glossiness	In the paper industry, low–quality paper produced effects on colour glossiness and smoothness
In the dyeing industry, exact colour is obtained. Does not produce undesirable shades.	In the dyeing industry, exact colour is not obtained. It produces undesirable shades.
In the textile industry, it helps to wash textiles, and yarn shows proper cleansing action	A large amount of soap waste develops precipitate getting deposited over cloth shows the dingy appearance

Soft Water	Hard Water
In sugar industry produces excellent quality sugar crystals	It affects the shape of sugar crystals. Small size or sugar powder formation takes place.
In domestic life does not affects the life of utensils and consumes the required amount of fuel for food preparation	In domestic life affects the life of utensils and a large amount of fuel required for food preparation.
It does not affect badly on skin and hair.	It affects skin and hair badly.
It is suitable for drinking hence helps for digestion, and does not produce any stones in body parts	It is not suitable for drinking, harmful effect on digestion. Also causes calcium oxalate crystals in the kidney and bladder to form a kidney stone

SAQ 1	The hardness of water is due to the presence of the salt of			
	1. Boron	2. Beryllium	3. Potassium	4. Magnesium

Key: 4

2.1.4. Unit of Hardness

Due to the calcium and magnesium salts, water becomes hard. The unit of hard water is expressed in terms of parts by weight of calcium carbonates. There are different systems to describe the hardness of the water.

a) Parts per million (ppm) b) French degree of hardness (^{0}Fr)
c) Degree clark (^{0}Cl) d) Milligrams per litre
e) Milliequivalent per litre

(a) Parts Per Million (ppm)

The number of parts by weight of calcium carbonate present per million parts by weight of water.

$$1 \text{ ppm} = \frac{1 \text{ part of } CaCO_3}{10^6 \text{ parts by weight of water}}$$

(b) French Degree of Hardness (^{0}Fr)

Number of parts by weight of $CaCO_3$ present in 100000 (or 10^5) parts by weight of water

$$1^0\text{French} = \frac{1 \text{ part of } CaCO_3}{10^5 \text{ parts by weight of water}}$$

(c) Degree Clark (^{0}Cl)

Number of parts by weight of calcium carbonate in 70000 parts by weight of water

$$1\ ^0\text{Clark} = \frac{1 \text{ part of } CaCO_3}{70{,}000 \text{ parts by weight of water}}$$

(Or) The number of grains of $CaCO_3$ equivalent hardness per gallon of water.

$$1\ ^0\text{Cl} = \frac{\text{No. of grains of } CaCO_3}{1 \text{ gallon of water}}$$

(d) Milligrams Per Litre (mg/L)

Number of milligrams of $CaCO_3$ equivalent hardness present per litre of water.

1 mg/L = 1 mg of $CaCO_3$ equivalent of hardness of 1L of water

But 1L of water weighs = 1 kg

= 1000g

=1000 × 1000 mg

= 10^6 mg

1mg/L = 1mg of $CaCO_3$ equivalent per 10^6 mg of water

= 1ppm

(e) Milliequivalent Per Litre (meq/L)

Number of milliequivalent of hardness is present per litre.
1meq/L= 1 meq of $CaCO_3$ per L of water
Calculation of meq/L for $CaCO_3$ molecule
Molecular weight of $CaCO_3$ = 100 g
Equivalent weight of $CaCO_3$ = 50 g = 50 × 10^{-3}g = 50 mg/L = 50 ppm

Table 2.2 Relation between Various Units of Hardness

Basic Unit	Conversion Factors				
	ppm	^{0}Fr	^{0}Cl	meq/L	mg/L
1 ppm	-----	0.1	0.07	0.02	1
1 ^{0}Fr	10	-----	0.7	0.2	10
1^{0}Cl	14.3	1.433	-----	0.286	14.3
meq/L	50	5	0.35	-----	50
mg/L	1	0.1	0.07	0.02	-----

SAQ 2	The hardness of water is conventionally expressed in terms of an equivalent amount of			
	1. $CaCO_3$	2. $MgCO_3$	3. Na_2SO_4	4. $NaHCO_3$

Key: 1

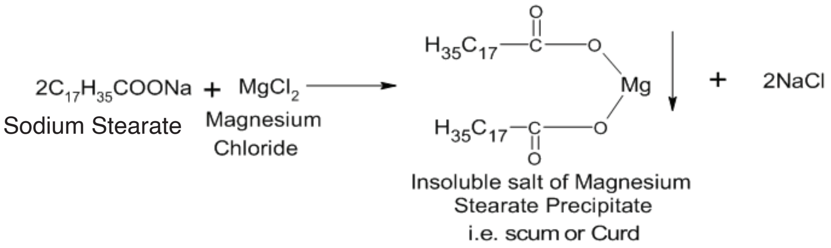
2.2 CAUSES OF HARD WATER

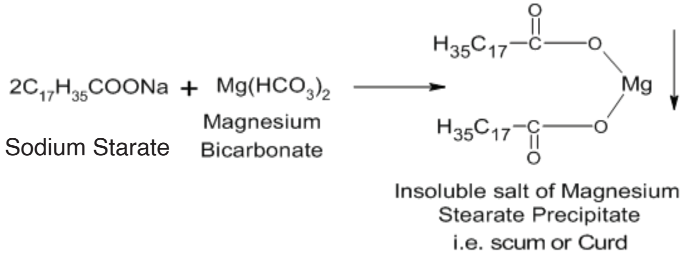
2.2.1 Causes of Poor Lathering of Soap in Hard Water

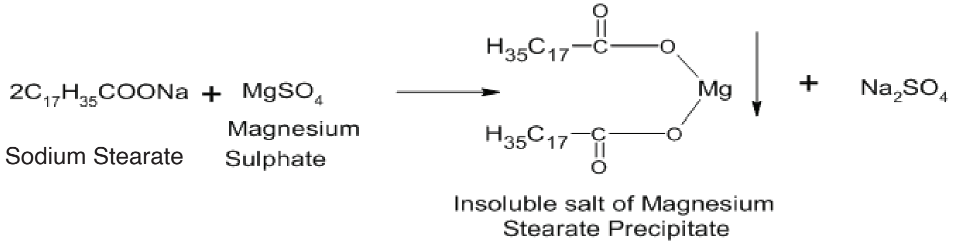
Water is a universal solvent. Hence it is used in the domestic and industrial sector for cleaning purpose. When water combines with soap,it forms lather. Soap is a mixture of sodium or potassium salt of higher fatty acid. Some commonly used acids are palmitic acid, oleic acid and stearic acid. Soap is soluble in water forming two poles as the salty end and the fatty end. These poles react with the dirt and show cleaning property.

Water containing dissolved salts like magnesium and calcium is mixed with soap, and insoluble salts of magnesium and calcium salts are obtained.

Reactions







When water contains calcium chloride, calcium bicarbonate and calcium sulphate, it shows a similar type of reactions as above The formed calcium and magnesium salts develop white precipitate called scum or curd, instead of lather. Hence dissolved salts present in water are responsible for the poor lathering of soap.

2.2.2 Problems Caused by the Use of Hard Water in the Boiler

Water is helpful to a great extent in several industries. However, when hard water used for different processes, it gives other ill effects. Water containing dissolved salts of sulphates, carbonates, chlorides of calcium, magnesium and iron salts have an adhesive impact on steam boilers. The manufacturing industries need water for a different purpose, out of which steam generation is of the utmost importance. Hence, water for raising steam in boilers must be soft and must not contain dissolved matter to avoid sludge, scale, priming and foaming problems in the boiler.

(A) Sludge

Due to the continuous boiling of water, the concentration of dissolved salt inside the boiler is increased. When the salt concentration reaches the saturation point, salts are thrown out of the water,precipitating on the inner wall of the boiler. [Fig.2.4]

The loose and slimy precipitate deposited on inner wall of boiler is known as **sludge.**

Excessive sludge formation disturbs the working of the boiler. It settles in the regions of poor water circulations such as pipe connection, plug opening, thereby causing even chocking of the pipes.

Properties of Sludge

- Sludges are soft and less permeable precipitate
- Sludges are poor conductors of heat.
- These are formed at comparatively cooler portions of the boiler.
- Sludges are formed by substances that have greater solubility in hot water.
  e.g. $MgCO_3$, $MgCl_2$, $CaCl_2$, $MgSO_4$ etc.

Prevention of the Sludge Formation

We can decrease sludge formation by

- using well soften water.
- frequently blowdown operation by drawing off a portion of the concentrated water.
- mechanical means by scrapping off the sludge with a wire brush.
- giving thermal shocks.

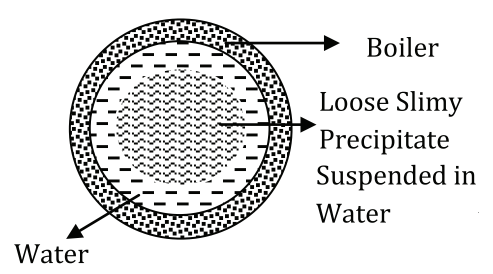


Fig. 2.4 Sludge Formation

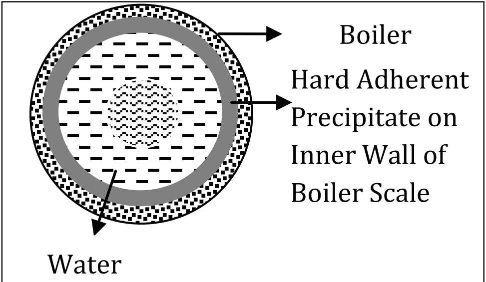


Fig. 2.5 Scale Formation

(B) Scale

While continuously boiling the water inside the boiler, the salt concentration reaches the saturation point, the salts are thrown out of the water in the form of precipitates on the inner wall of the boiler. They are formed due to the presence of sulphate and silicates of calcium and magnesium [Fig. 2.5].

The hard adhering coating deposited on inner wall of boiler is known as scale.

Properties of Scale

- Scale is very hard and firmly adhered to the boiler
- It is difficult to remove them, even with the hammer or chisel.
- It is bad conductors of heat.

Prevention of the Scale Formation

- The formed precipitate can be removed by thermal shocks with chisel hammer treatment.
- Internal conditioning with different chemicals as phosphate, carbonate, calgon, tannin, agar gel, sodium aluminate, EDTA.

Table 2.3 Difference between Sludge and Scale

Sludge	Scale
Soft, loose and slimy precipitate	Hard deposits
Non-adherent deposits and can be easily removed	Stick very firmly to the inner surface of the boiler and are very difficult to remove
Softer and less permeable	Harder and more permeable
Poor conductor of heat	Bad conductor of heat
Formed generally at the colder portion of the boiler	Formed generally at the hotter part of the boiler
Decreases efficiency of the boiler but are less dangerous.	Decreases efficiency of the boiler and more dangerous.
There will be fewer chances of explosion due to sludges formation.	There will be more chances of explosion due to scale formation.
They are generally formed due to salts like $CaCl_2$, $MgCl_2$, $MgSO_4$, $MgCO_3$ in the water.	They are generally formed due to salts like $CaSO_4$, $Mg(OH)_2$, $CaCO_3$, $CaSiO_3$, $Ca_3(PO_4)_2$, CaO.
The precipitate can be removed by blowdown operation, scrapers and brushing	The precipitate can be removed by different methods like thermal shocks, chiselling, hammer treatment along with some chemical like HCl, phosphate, carbonate, calgon, tannin, agar gel, sodium aluminate, EDTA.

(C) Priming

When the boiler is being steamed rapidly, some liquid water particles are mixed with the steam.

Priming is the conveyer of variable amounts of droplets of water in the steam.

(D) Foaming

Foaming is the production of persistent foam and bubbles in boilers.

Formed bubbles do not break easily. Foaming is generally due to the presence of substance like oils.

Causes of Priming and Foaming

Causes of priming and foaming are as follows

- Presence of a large amount of dissolved solid.
- High steam velocities.
- Sudden boiling.
- Improper boiler designs.
- The sudden increase in steam production rate.

Priming and Foaming can be Avoided by

- fitting mechanical steam purifiers.
- avoiding rapid change in steaming rate.
- maintaining the low water level in boilers
- efficient softening and filtration of the boiler feedwater. Adding antifoaming chemicals like castor oil.
- removing oil from boiler water by adding compounds like sodium aluminate.

Problems due to priming and Foaming

Due to priming and foaming following problems are generated in the boiler

- Causes caustic embrittlement
- Chocking of outlets
- Do not allow steam to flow quickly due to the presence of foam.

Effect of Priming and Foaming

In boiler, water priming and foaming usually occur together because

- The actual height of the water column cannot be adequately judged, thereby making the maintenance of the boiler pressure becomes difficult.
- Dissolved salts in water are carried by wet steam to different machinery parts, where salt gets deposited as water evaporates.
- Life of machinery decreases

(E) Corrosion

Boiler corrosion is the decay or destruction of boiler material by a chemical or electrochemical environment. Corrosion of boiler takes place due to following reasons :

- Dissolved oxygen
- Dissolved carbon dioxide
- Dissolved salts

Causes of Boiler Corrosion

(i) Dissolved Oxygen

Dissolved oxygen present in water interacts with boiler material at steaming temperature to form the ferrous hydroxide. Formed ferrous hydroxide further reacts with oxygen to form ferric oxide.

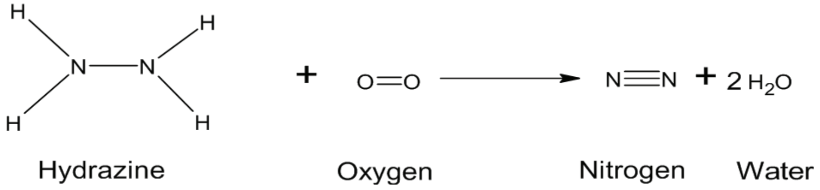
$$2Fe + 2H_2O + O_2 \longrightarrow 2Fe(OH)_2\downarrow$$

$$4Fe(OH)_2 + O_2 \longrightarrow 2[Fe_2O_3.2H_2O]\downarrow$$

(a) Removal of Oxygen by using Chemicals

There are different chemicals like hydrazine, sodium sulphate, tannin, which are used to remove dissolved oxygen. In the case of hydrazine reacts with dissolved oxygen to form nitrogen and water.

Suppose we use a dissolved oxygen sensor and find that amount of dissolved oxygen in boiler water is increased; in that case, these chemicals react with dissolved oxygen and easily remove dissolved oxygen from boiler water.



Dissolved nitrogen is harmless, and there is no change in the percentage of dissolved solids after the addition of nitrogen.

(b) Removal of Dissolved Oxygen by Heating

Water is passed through the tower, which contains perforated plates, heating arrangement from the side and vacuum pump arrangement. High-temperature low pressure, and large exposed surface reduce the dissolved oxygen in water.[Fig. 2.6].

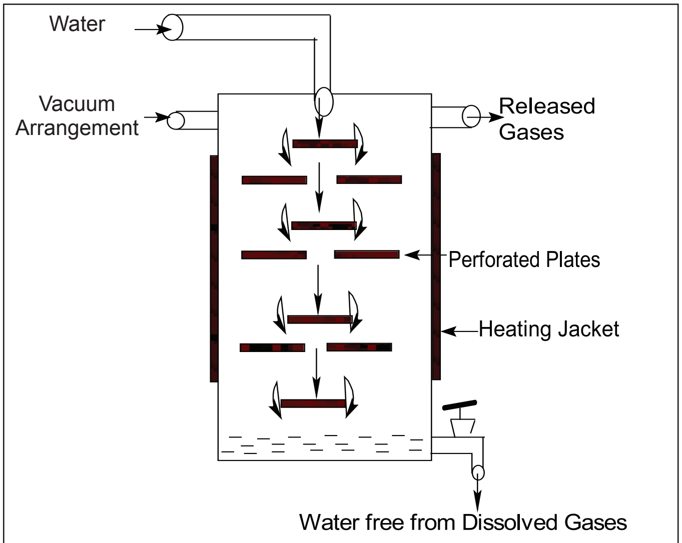


Fig. 2.6 Removal of Dissolved Oxygen by Heating

(ii) Dissolved CO_2

Water associated with dissolved CO_2 forms carbonic acid, which has a slow corrosive effect on boiler material. Water containing bicarbonates is also the source of CO_2

$$CO_2 + H_2O \longrightarrow \underset{\text{Carbonic Acid}}{H_2CO_3}$$

$Mg(HCO_3)_2 \longrightarrow MgCO_3 + H_2O + CO_2\uparrow$

Magnesium Bicarbonates Magnesium Carbonate

Removal of CO_2 by using ammonia

Carbon dioxide can be removed by adding calculated amount of ammonia

$H_2O + NH_3 \longrightarrow NH_4OH$

Ammonia Ammonium Hydroxide

$NH_4OH + CO_2 \longrightarrow (NH_4)_2CO_3 + H_2O$

Ammonium Carbonate

Removal of Carbon dioxide by Heating

Water associated with different types of gases is required to be removed by heating the water at high temperature. Low pressure reduces the dissolved CO_2 [Fig.2.6]. If it is not removed they are responsible for corrosion of the boiler material.

(iii) Dissolved Salts

When Magnesium chloride combines with water, it forms magnesium hydroxide along with hydrochloric acid as a byproduct.

$MgCl_2 + 2H_2O \longrightarrow Mg(OH)_2\downarrow + 2HCl$

byproduct

The liberated acid reacts with the iron metal of the boiler in chain-like reactions producing HCl again and again. Hence the presence of a small amount of $MgCl_2$ will cause corrosion of iron to a large extent.

$Fe + 2HCl \longrightarrow FeCl_2\downarrow + H_2$

Ferrous Chloride

$FeCl_2 + 2H_2O \longrightarrow Fe(OH)_2\downarrow + 2HCl$

Ferrous chloride Ferrous hydroxide

During the water softening process, a small quantity of sodium carbonate is added. In high-pressure boilers, sodium carbonate decomposes to give sodium hydroxide and carbon dioxide.

$Na_2CO_3 + H_2O \longrightarrow 2NaOH + CO_2\uparrow$

Due to the formation of sodium hydroxide, water becomes alkaline. The number of minute cracks are observed on the inner wall of boiler. This alkaline water flows into such minute cracks by capillary action. Here due to water evaporation, dissolved caustic soda is left behind. The amount of caustic soda goes on increasing due to progressive evaporation. The alkaline action of caustic soda attacks the surrounding areas of cracks, thereby dissolving the iron material of the boiler.

Precautions to avoid Corrosion due to Salts

- Supply the water which is free from salts like $MgCl_2$.
- By using sodium phosphate instead of sodium carbonate for water softening.
- By adding tannin or lignin as additives to the boiler water since these block the minute cracks
- By adjusting the alkalinity of water to an optimum level (pH 7-8)

2.2.3 Quantitative Determination of Water Hardness by EDTA Method, Total Dissolved Solids (TDS) & Alkalinity Estimation

The practical performance /experiments under above title are mentioned at the end of this unit.

(a) Quantitative Determination of Water Hardness by EDTA Method

This method is used to determine the hardness of water using the EBT (Eriochrome Black T) indicator and EDTA (Ethylene Diamine Tetra Acetic acid). Eriochrome Black-T (EBT) indicator is an alcoholic solution of blue dye used for titration with pH of about 10. When Eriochrome Black T indicator is added to hard water buffered to about 10 pH, a wine red unstable complex is formed. Thus

$$M^{2+} + \text{EBT} \longrightarrow [\text{M - EBT}]$$

Blue Wine Red Colour Unstable complex

During the titration, EDTA reacts with Ca-EBT or Mg-EBTunstable complex and forms a stable complex of Ca-EDTA or Mg-EDTA and releases EBT into the solution. However, when nearly all M^{2+} (Ca^{2+} or Mg^{2+}) ions have formed [M-EDTA] complex, then the next drop of EDTA added displaces the EBT indicator from [M-EBT] complex and wine red colour changes to blue colour (due to EBT). Hence the endpoint of the titration is wine red to blue colour.

$$[\text{M-EBT}] + \text{EDTA} \longrightarrow [\text{M-EDTA}] + \text{EBT}$$

Unstable Stable complex Blue
Wine Red

The structure of EDTA is present in disodium salt [Fig. 2.7] it yields the anion, which forms complex ions with Ca^{2+} and Mg^{2+} ions [Fig. 2.8].

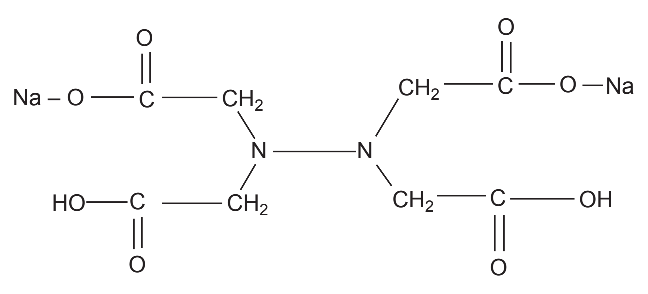


Fig. 2.7 Ethylene Diamine Tetra Acetic acid (EDTA)

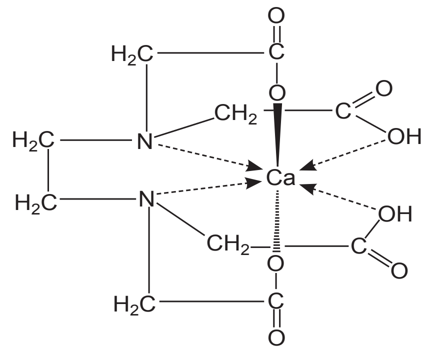


Fig. 2.8 Ca^{2+} EDTA Complex

We will be learning about the determination of total hardness of given sample of water using standard EDTA method and determination of the alkalinity of a given water sample using 0.01M sulphuric acid through practical performance in the laboratory.

Advantages of EDTA method

This method is preferable to the other methods because of the

(i) Greater accuracy
(ii) Convenience (iii) More rapid procedure

(b) Quantitative Determination of Water Hardness and Total Dissolved Solids (TDS)

For determination of residue on evaporation or total dissolved solid, measure out volume of the filtered sample required for the main analysis and evaporate to dryness in porcelain dish. Dry the dish contents one and half hour at 1800C and weigh. The weight obtained is often reported as "total dissolved solid"

(c) Quantitative Determination of Water Hardness by Alkalinity Estimation

Alkalinity is defined as the measure of the acid neutralising capacity of water. The alkalinity of water is attributed to the presence of the

- Caustic alkalinity (due to OH^- and CO_3^{2-} ions)
- Temporary hardness (due to HCO_3^- ions)

These can be estimated separately by titration against standard sulphuric acid, using phenolphthalein and methyl orange as indicators. The determination is based on the following reactions:

(i) $[OH^-] + [H^+] \longrightarrow H_2O$

(ii) $[CO_3^{2-}] + [H^+] \longrightarrow [HCO_3^-](M)$

Phenolphthalein (P)pH=8.3 P-alkalinity

(iii) $[HCO_3^-] + [H^+] \longrightarrow H_2O + CO_2$

Methyl Orange pH=4.5 Total alkalinity or M-alkalinity

The titration of the water sample against a standard acid up to the phenolphthalein end-point marks the completion of the reaction (i) and (ii) only. This amount of acid used thus corresponds to hydroxide plus one half of the normal carbonate present. On the other hand, titration of the water sample against a standard acid to methyl orange end-point marks the completion of reaction i,ii and iii. Hence the amount of acid used after the phenolphthalein end-point corresponds to one-half of normal carbonate plus all the bicarbonates, while the total amount of acid used represents the total alkalinity (due to hydroxide, bicarbonates and carbonate ions)

$$P = OH^- + \frac{1}{2} CO_3^{2-}$$

$$M = OH^- + CO_3^{2-} + HCO_3^-$$

The possible combinations of ions causing alkalinity in water are: (i) OH^- only or (ii) CO_3^{2-} only or (iii) HCO_3^- only or iv) OH^- and CO_3^{2-} together or CO_3^{2-} and HCO_3^- together.

The possibility of OH^- and HCO_3^- ions together is ruled out, because they combine instantaneously to form CO_3^{2-} ions.

$$OH + HCO_3^- \longrightarrow CO_3^{2-} + H_2O$$

e.g. $NaOH + NaHCO_3 \longrightarrow Na_2CO_3 + H_2O$

Thus OH^- and HCO_3^- ions can not exist together in water. On the basis of same reasoning, all the three (OH^-, CO_3^{2-} and HCO_3^-) can not exist together.

Table 2.4 Calculation of Alkalinity of Water

Alkalinity Condition	Alkalinity due to the Presence of		
	OH^- (ppm)	CO_3^{2-} (ppm)	HCO_3^-(ppm)
P= 0	0	0	M
P = M	P = M	0	0
$P = \frac{1}{2}M$	0	2P	0
$P < \frac{1}{2}$ M	0	2P	(M-2P)
$P > \frac{1}{2}$ M	(2P-M)	2(M-P)	0

Interpretation of table 2.4 is as follows

(1) When P=0, both OH^- and CO_3^{2-} are absent and alkalinity, in that case, is due to HCO_3^- only.

(2) When P=M, only OH^- ions are present because neither CO_3^{2-} nor HCO_3^- ions are present. Thus, alkalinity due to OH^- =P=M

(3) When P= $\frac{1}{2}$M, only carbonate ions are present since, half of the carbonate neutralisation reaction $CO_3^{2-} + H \longrightarrow HCO_3^-$ takes place with phenolphthalein while complete carbonate neutralisation reaction $CO_3^{2-} + H^+ \longrightarrow HCO_3^-$;

$HCO_3^- + H^+ \longrightarrow H_2O + CO_2$ occurs when the methyl orange indicator is used.

Thus alkalinity due to CO_3^{2-} =2P

(4) When P<$\frac{1}{2}$M In this case, besides CO_3^{2-}, HCO_3^- ions are also present. Now alkalinity due to

CO_3^{2-} = 2P Therefore, alkalinity due to HCO_3^- = (M–2P)

(5) When P>$\frac{1}{2}$M In this case, besides CO_3^{2-}, OH^- ions are also present. Half of CO_3^{2-} (i.e.

$HCO_3^- + H^+ \longrightarrow CO_2 + H_2O$ equal to (M–P)

So alkalinity due to complete CO_3^{2-} = 2(M–P)

Therefore, alkalinity due to OH^- = M-2(M–P) = (2P–M)

2.3 WATER SOFTENING TECHNIQUES

2.3.1 An Introduction

Water used for various industrial purposes e.g. steam generation should be pure and free from hardness producing salts before use. The process of removing hardness producing salts from water is known as softening of water. These salts can be removed from water by two types of treatment processes, as below

Treatment of Hard Water

External Treatment
(i) SodaLime Process
(ii) Zeolite Process
(iii) Ion Exchange Process

Internal Treatment
(i) Colloidal
(ii) Phosphate
(iii) Calogen

External treatment methods are most commonly used in industries for softening of water.

2.3.2 Soda Lime Process

In this process, lime (CaO) or hydrated lime [$Ca(OH)_2$] and soda ash[Na_2CO_3] are used for the precipitation process of softening. The lime is required for the precipitation of compounds causing temporary or carbonate hardness. Soda ash is used for the precipitation of compound causing permanent hardness.

(i) For carbonate or temporary hardness

$$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3 \downarrow + H_2O$$
$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3 \downarrow + 2H_2O$$
$$Mg(HCO_3)_2 + Ca(OH)_2 \longrightarrow MgCO_3 \downarrow + CaCO_3 \downarrow + 2H_2O$$

$MgCO_3$ formed further reacts in following manner

$$MgCO_3 + Ca(OH)_2 \longrightarrow Mg(OH)_2 \downarrow + CaCO_3 \downarrow$$

(ii) For non carbonate or permanent hardness

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3 \downarrow + Na_2SO_4 \downarrow$$
$$MgSO_4 + Ca(OH)_2 + Na_2CO_3 \longrightarrow Mg(OH)_2 \downarrow + CaCO_3 \downarrow + Na_2SO_4$$
$$MgCl_2 + Ca(OH)_2 \longrightarrow Mg(OH)_2 \downarrow + CaCl_2$$
$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3 \downarrow + 2NaCl$$

From the above it is clear that in case of temporary hardness, each unit of calcium carbonate requires one mole of lime whereas each unit of magnesium bicarbonate requires 1 mole of lime In case of permanent hardness, magnesium salt required 1 mole of lime and soda ash each, whereas calcium salt requires one mole of soda ash only.

If there is excess lime in soft water, the water will become hard due to soluble calcium hydroxide. Hence required amount of calcium hydroxide and soda ash is added to hard water for softening. Lime soda method can be classified into cold lime soda process and hot lime soda process.

(A) Cold Soda Lime Process

Lime and soda ash are added to hard water in chemical tank and are mixed thoroughly. The calcium carbonate formed during the reaction does not precipitate, but form supersaturated solution. To prevent supersaturation, some previously formed sludge is mixed with treated water. Coagulants or flocculants such as aluminium sulphate, sodium aluminate are added to help the formation of coarse precipitate. Sodium aluminate helps in the removal of silica, if present in water.

$$NaAlO_2 + 2H_2O \longrightarrow NaOH + Al(OH)_3 \downarrow$$

Sod. Aluminate

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 \downarrow + 3CaSO_4 + 6CO_2 \uparrow$$

Coagulant Hardness in water

Kinds of Softener –

Cold soda lime process uses two types of softeners

Intermittent Types Softener

In this method, lime and soda ash are mixed with raw water with continuous stirring [Fig. 2.9]. Small amount of precipitate from previous filtration is added to prevent super saturation. When the reaction is complete, precipitate is allowed to settle down and the sludge is taken out . Clear soft water is taken out in another tank through a pipe.

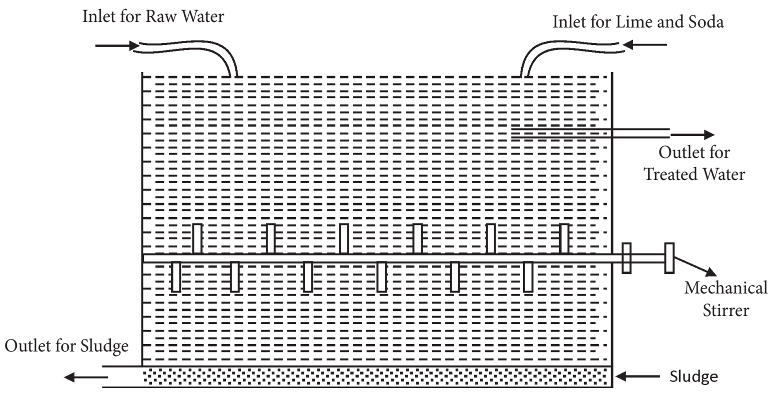


Fig 2.9 Intermittent Type Softener

Continuous Type Softener

It consists of big steel tank with inner and outer chambers. Raw material and required chemicals are put into the inner chamber with continuous stirring at room temperature as shown in [Fig. 2.10]. Softening of water occurs in inner chamber. Soft water moves upward in the outer chamber where all sludge is removed after complete filtration. Filtered water comes out through the water outlet and sludge is removed from the bottom.

For softening the boiler feed water, cold soda lime method is not used because -

- Softened water does not have zero hardness.
- Residual hardness is harmful for water tubes in the boiler

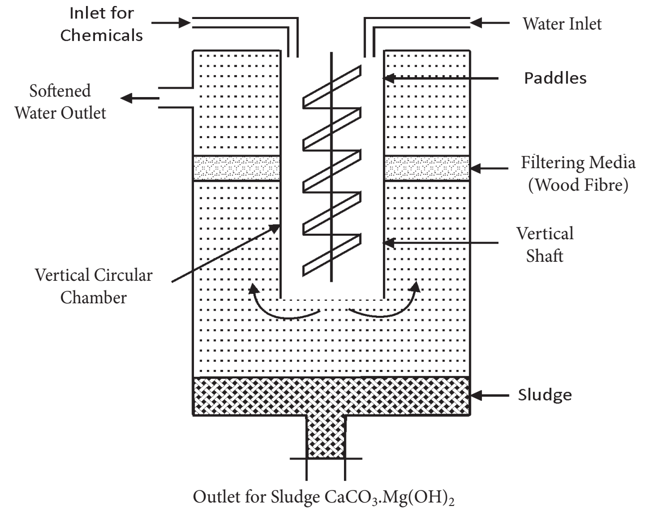


Fig 2.10 Continuous Type Softener

(B) Hot Soda Lime Process

It is similar to cold lime soda process except that mixture of raw water, softening chemicals, and small amount of sludge are heated at temperature of 80^0 to 150^0 [Fig. 2.11]. By heating, the reaction is much faster and the precipitation is done in shorter time. Also the sludge formed is settled down quickly. No coagulants are required in this method. The softened water has hardness of 22 - 25 ppm.

Advantages of Hot Soda Lime Process over Cold Soda Lime Process

- The reaction is faster and takes less time.

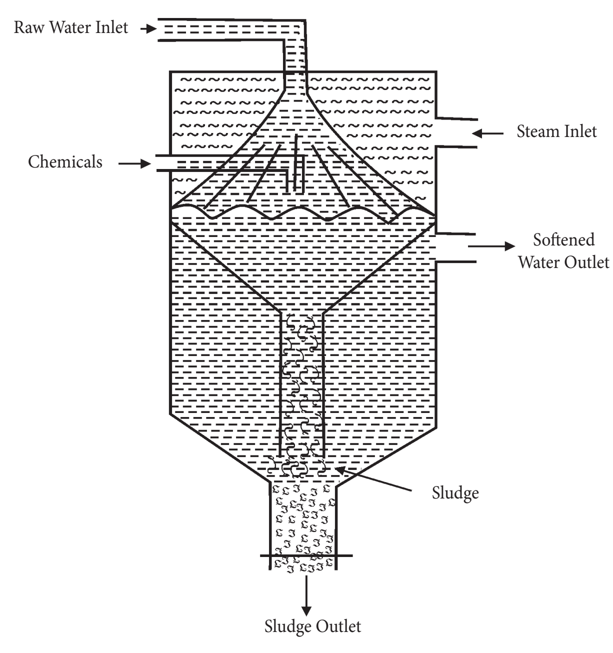


Fig 2.11 Continuous Type Hot Sodalime Softener

- By adding magnesium oxide and lime at 50^0C, silica also get precipitated.
- The quantity of chemical used is reduced.
- The precipitate formed is granular, more dense and can easily be removed.
- The temporary hardness, free carbon dioxide, dissolved oxygen, and other dissolved gases are removed by preheating.

Disadvantages of Soda Lime Process

- It is not suitable for turbid and acidic water.
- Huge amount of precipitate is formed which creates the disposal problem.
- The effluent cannot be reduced to zero hardness.
- Water with excessive hardness cannot be softened by this method.
- Not suitable for many industrial purposes as the water obtained is supersaturated with $CaCO_3$.

SAQ 3	Slaked lime is			
	1. $Ca(OH)_2$	2. CaO	3. $CaCO_3$	4. $Ca(HCO_3)_2$

Key : 1

SAQ 4	Permanent hardness in water is removed by-			
	1. CaO	2. $Ca(HCO_3)_2$	3. Na_2CO_3	4. $Ca(OH)_2$

Key : 3

2.3.3 Zeolite Process or Permutit Process

This process involves softening of water by natural or artificial zeolite. Zeolite is hydrated sodium aluminosilicate.

Zeolites are substances that are insoluble in water and can act as base exchanger when placed in contact with water containing cations. Zeolites are commercially known as permutit and are of two main types i.e. natural and synthetic.

Natural Zeolites

They are non-porous, more durable and are derived from green sands by washing, heating and treating with sodium-hydroxide (NaOH).

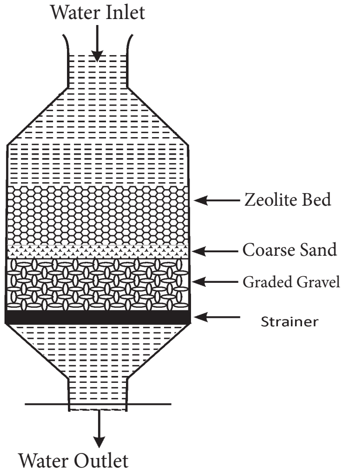


Fig 2.12 Zeolite Softener

Synthetic Zeolites

They are porous and possess a gel structure. They have higher exchange capacity per unit weight. They are prepared from solution of sodium silicate and aluminium hydroxide.They may also be prepared by heating together.

Examples

Natural Zeolites	**Synthetic Zeolites**
Thomsonite $(Na_2O,CaO).Al_2O_3.2SiO_2.2\frac{1}{2}H_2O$,	ChinaClay, Feldspar, and Sodaash
Natrolite $Na_2O,Al_2O_3.3SiO_2.2H_2O$	Solution of sodium silicate & $Al_2(SO_4)_3$
Laumontite $CaO.Al_2O_3.4SiO_2.4H_2O$	Solution of sodium silicate and $NaAlO_2$
Harmotome $(BaO.K_2O).Al_2O_3.5SiO_2.5H_2O$	
Stilbite $(Na_2O.CaO).Al_2O_3.6SiO_2,6H_2O$	
Brewsterite $(BaO.SrO.CaO).Al_2O_3.6SiO_2.5H_2O$	
Pitlolite $(CaO.K_2O.Na_2O).Al_2O_3.10SiO_2.5H_2O$	

(A) Process

Zeolite softener consists of a steel tank with different layers as shown in [Fig. 2.12]. When water is poured from the top into the different layers,the following reaction takes place.

$$Na_2Z + Ca(HCO_3)_2 \longrightarrow CaZ + 2NaHCO_3$$
$$Na_2Z + Mg(HCO_3)_2 \longrightarrow MgZ + 2NaHCO_3$$

Sodium zeolite are used in water softening and is represented as Na_2Z, where Z stands for insoluble zeolite radical framework. They can exchange basic radicals hence are also called as base exchanger. Here $Z = Al_2Si_2O_8.xH_2O$

$$Na_2Z + CaCl_2 \longrightarrow CaZ + 2NaCl$$
$$Na_2Z + MgCl_2 \longrightarrow MgZ + 2NaCl$$
$$Na_2Z + CaSO_4 \longrightarrow CaZ + Na_2SO_4$$
$$Na_2Z + MgSO_4 \longrightarrow MgZ + Na_2SO_4$$
$$\underset{\text{Exhausted Zeolite}}{CaZ + 2NaCl} \longrightarrow \underset{\text{Regenerated Zeolite}}{Na_2Z + CaCl_2}$$
$$MgZ + 2NaCl \longrightarrow Na_2Z + MgCl_2$$

Regeneration

When we pass litres of water through zeolite tank, hardness causing Ca^{2+} and $Mg^{2+}$are deposited over the zeolite while loosely bonded sodium ions goes along with water. After passing certain amount of water, all Na^+ ions are replaced by Ca^{2+} and Mg^{2+} cations.In such case zeolite stops working i.e. after passing water through zeolite it is unable to remove hardness causing ions from water. In another words we can say that zeolite bed is exhausted i.e. saturated with Ca^{2+} ions and Mg^{2+} ions. It can be regenerated / recharged by using the NaCl solution (Brine solution).Sodium nitrate and sodium sulphate can also be used. Hence we can use regenerated zeolite for further removing the hardness. The regeneration steps comprises of back wasting, salting or brining and rinsing before reuse.

(B) Advantages

- The equipment occupies a small space and is easy to operate.
- Zero hardness water can be produced through this.
- No sludge formation occurs during the process.
- The method is cheap as the permutit can be regenerated.
- It automatically adjusts to the water of different hardness.
- The plant can be installed in the water supply line itself, avoiding double pumping.

(C) Limitations

- The feed water must be free from suspended particles; otherwise, the permutit will get clogged.
- Excess of acid or alkali present in the water must be neutralised to prevent the burning of zeolite. Thus pH of the water should be maintained to around 7.
- Regeneration of permutit is very hard when it is associated with Fe^{2+} and Mn^{2+} salts.
- Water treated by the zeolite process contains about 25% more dissolved solids than that treated by the soda-lime process.
- Treated water contains more sodium salts.
- All acidic ions such as HCO_3^- and CO_3^{2-} are left in softened water.
- Highly turbid water cannot be treated by this method.

SAQ 5	The exhausted zeolite is regenerated by-			
	1. NaCl	2. $Ca(HCO_3)_2$	3. $CaSO_4$	4. $NaHCO_3$

Key: 1

(D) Comparison between the Zeolite Process and Soda-Lime Process

The comparison between the zeolite process and the soda-lime process is given below in table 2.5.

Table 2.5 Comparison between the Zeolite Process and Soda-Lime Process

Sr. No.	Points of Difference	Zeolite Process	Soda-LimeProcess
1	Size of plant	Compact and small	Bulky and large
2	Supervision required	Automatic and easy to operate and no skilled supervision required	Skilled supervision is required for successful working
3	Sludge problem	No sludge is formed and hence there is no problem of its disposal	Large quantity of sludge is formed which needs to be disposed off by some suitable method
4	Treatment of acidic water	It cannot be used for treating acidic water.	No such limitation.

Sr. No.	Points of Difference	Zeolite Process	Soda-LimeProcess
5	Issue of settling, coagulation, filteration, sludge removal	It involves no problem of settling, coagulation, filteration and removal of sludges and precipitates	It involves difficulty in settling, coagulation, filteration and removal of precipitates
6	Post treatment	No post treatment is required	Recarbonation is needed
7	Results obtained	Water of zero hardness can be obtained hence useful for industrial supplies too.	This can produce water of hardness not less than 50 mg/L hence it is useful for public water supplies only.
8	Removal of iron and manganese	Not suitable for water containing iron and manganese, because iron zeolite and manganese zeolite may be formed which cannot be reconverted into sodium zeolite.	Can remove iron and manganese from water to some extent.
9	Bactericidal effect	Bactericidal effect does not exist in this process.	There is likelihood of killing of bacteria in this process.
10	pH value of treated Water	pH value of water treated by this process is not affected.	pH value of water treated by this process is increased which results in decrease in corrosion of the distribution system.
11	Care needed in handling materials	Salt solution is required to be handled which does not require much care.	Careful handling is required because the materials, i.e., lime and soda are corrosive.
12	Economy	Process is relatively costly.	Process is economical.
13	Extent of hardness which can be treated	Raw water with hardness greater than 800 mg/L cannot be easily and economically treated	Excessively hard waters, particularly those which are high in magnesium hardness can be treated.
14	Allowable turbidities in raw water	Highly turbid waters are difficult to be treated because of the deposition and obstruction of suspended impurities around zeolite particles .	Highly turbid and acidic waters can be treated.
15	Sodium salts in treated water	Treated water contains larger amount of sodium salts than original water	Treated water contains lesser amount of sodium salts .
16	Dissolved solid	Treated water contains more dissolved solids	Treated water contains lesser amount of dissolved solids

2.3.4 Ion Exchange Process for Water Softening

In an ion exchanges process,a reversible exchange of ions take place between the stationary ion-exchange phase and the mobile external liquid phase. Certain synthetic organic compounds possess the property of exchanging ions (like zeolite). Such compounds are known as resins

[Fig. 2.13]. Ion exchange resins are insoluble, cross linked, long chain organic polymers. Microporous structure and the functional groups attached to them are responsible for ion exchanging properties. The purely synthetic organic exchanges are made by Polycondensation and Polymerisations.

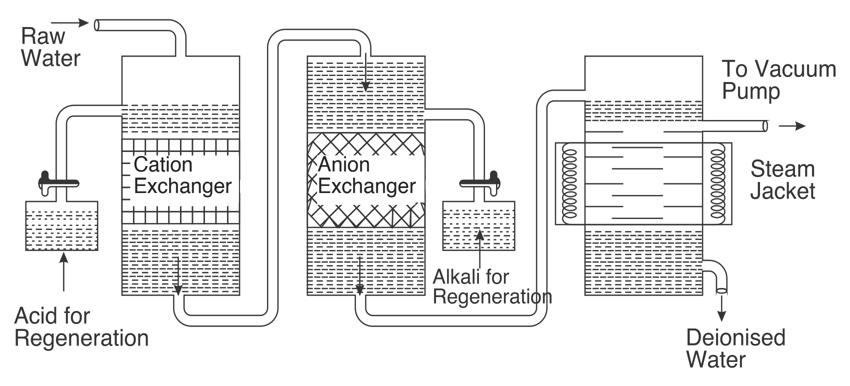


Fig. 2.13 Demineralization of Water

The functional groups are then introduced into the cross-linked resin network, either by subsequent treatment of the resin or by introducing the functional groups into the starting material itself. It is these functional groups which decide the nature of the exchanger (i.e., cationic or anionic). Based on the acidity or basicity of the functional group, exchangers are further classified as follows:

Type of Ion-exchanger	Functional Groups
Strongly acidic cation exchangers	SO_3H
Moderately strong cation exchangers	$-PO(OH)_2$
Weakly acidic cation exchangers	$-COOH$ or $-OH$
Strongly basic anion exchanger	NR^{3+}; $=P+$ $-CH_3$; etc.
Weakly basic anion exchanger	NH_2; (C_2H_4) x (NH)y-

(A) Types of Ion Exchange Resins

Cation exchange resins: These resins are capable of exchanging cations by H^+ ions. Cation exchanger resin can be represented as RH_2

Anion exchange resins: These resins are capable of exchanging anions by OH^- ions. Anion exchanger resin can be represented as $R'(OH)_2$

(B) Properties of Ion Exchanger

For effective water treatment, ion exchangers should possess the following properties-

1. Ion exchange resins should be non-toxic.

2. They should not decolourise the water being treated.
3. They should possess a high ion-exchange capacity. (It depends on the total number of ion active groups per unit weight to the exchanger and is expressed as milli equivalents per gram of the exchanger).
4. They should be physically durable, cheap and commonly available.
5. They should be resistant to chemical attack.
6. They must be capable of being regenerated and back-washed easily and economically.
7. They should have a large surface area since ion-exchange is a surface phenomenon.
8. Their resistance to flow must be compatible with hydraulic requirements.

(C) Process

It consist of two cylindrical towers, one cation exchanger and another anion exchanger. [Fig.2.13] Cation exchanger removes all the cations Ca^{2+}, Mg^{2+},Na^+, Fe^{2+} and releases H^+ ions. Thus Cl^-, SO_4^{2-} bicarbonates are converted into corresponding acids HCl, H_2SO_4 and H_2CO_3. Thus water coming from the cation exchanger is free from all cations, but it is acidic.

The hard water is passed through a cation exchange column, which removes all the cations like Ca^{2+}, Mg^{2+}, etc. from it, and the equivalent amount of H^+ ions are released from this column to water as below.

$$RH_2 + CaCl_2 \longrightarrow RCa + 2HCl$$
$$RH_2 + MgSO_4 \longrightarrow RMg + 2HSO_4$$
$$RH_2 + Na_2CO_3 \longrightarrow RNa_2 + H_2CO_3$$

This acidic water is then passed through another tower containing an anion exchanger, where acids are converted into water.

In anion exchanger, following reactions take place

$$R'(OH)_2 + 2HCl \longrightarrow R'Cl_2 + 2H_2O$$
$$R'(OH)_2 + H_2SO_4 \longrightarrow R'SO_4 + 2H_2O$$
$$R'(OH)_2 + H_2CO_3 \longrightarrow R'CO_3 + 2H_2O$$

Regeneration

When the cation exchanger gets exhausted,it is regenerated by passing the dilute acid (i.e. with HCl or H_2SO_4)solution.

$$RCa + 2HCl \longrightarrow RH_2 + CaCl_2$$
$$RMg + 2HCl \longrightarrow RH_2 + MgCl_2$$

Similarly exhausted anion exchanger is regenerated by passing a dilute solution of alkali through the second tower, i.e. with NaOH or KOH

$$R'Cl_2 + 2NaOH \longrightarrow R'(OH)_2 + 2NaCl$$
$$R'SO_4 + 2NaOH \longrightarrow R'(OH)_2 + Na_2SO_4$$

2.3.4(D) Advantages

(i) Highly acidic or alkaline water can be softened by this method.

(ii) As this method produces water of very low hardness ,it is used for treating water for use in high-pressure boilers .

(E) Disadvantages

(i) The equipment is costly and also more expensive chemicals are needed.

(ii) If water contains turbidity, then the output of the process is reduced. If it is more, it has to be removed first by coagulation and filtration.

2.4 MUNICIPAL WATER TREATMENT

2.4.1 Municipal Water Treatment- An Introduction

Safe water is essential for all domestic uses that include drinking, food preparation and personal hygiene. The World Health Organisation (2017) defines safe drinking water as water that does not have any risk to health when consumed over a period of time, including different sensitivities that may occur between life stages.

River and wells are common sources of water which are used by municipalities. This water have several undesirable components that are harmful for human health. Water quality data shows that organic and bacterial contamination are becoming increasingly critical in water bodies leading to gradual degradation of water quality. Biological Oxygen Demand (BOD) for most of the rivers of India are increasing and exceeding the standards. Waterborne diseases are rampant in India due to high levels of biological contamination of water leading to cholera, acute diarrhoea, typhoid, hepatitis etc.

Inorganic pollutants in water can be extremely harmful and lead to a range of chronic and fatal health problems ranging from poisoning to organ damage and cancers. For example, high levels of arsenic, lead, asbestos, cyanide, copper etc in water can be extremely harmful to health. Excessive levels of fluoride can lead to problems like dental and skeletal fluorosis, arsenicosis due to high levels of arsenic and endocrine disruptions and neurological damage due to presence of excessive amounts of mercury.Other organic and radiological contaminants can also lead to cancers, liver and kidney damage, reproductive and endocrine disorders, birth defects etc.

Studies by the Central Water Commission (2015) also show that rivers (surface drinking water sources) in India are loaded with toxic heavy metals such as lead, arsenic, copper, cadmium, mercury and nickel that are highly toxic and carcinogenic. The level of these components are far beyond standards prescribed by Indian Council of Medical Research (ICMR) and Bureau of Indian Standards (BIS).

Interesting fact : 1.8 billion people use a source of drinking water contaminated with faeces, putting them at risk of contracting cholera, dysentery, typhoid and polio. (WHO/ UNICEF 2015)

Looking to above facts, it becomes very important to treat the contaminated water.Municipal water supply is the most challenging and much needed to be addressed to remove undesirable components that are harmful for human health. Depending upon the type of impurities, different methods are employed for purification of water for potable use as below:

- **Screening:** Removes the floating materials like leaves.
- **Sedimentation:** Removes suspended impurities likes and clay etc.
- **Coagulation:** Removes finely divided suspended particles.
- **Filteration:** Removes colloidal impurities and large organisms.
- **Disinfection:** Kills the bacteria.

2.4.2 Screening

The raw water is allowed to pass through screens of appropriate size. Floating impurities like rags, paper, leaves, etc., are screened by the sieve and water is passed through the holes.

2.4.3 Sedimentation

Sedimentation is a process of removing suspended impurities. Suspended particles settle down due to the force of gravity. This process takes two to eight hours and removes 70%–75% of suspended impurities. It is done in large settlement tanks or reservoir.

2.4.4 Coagulation

Coagulation is the process by which the fine, suspended, and colloidal impurities are removed from the water by the addition of suitable chemicals as coagulants. The finely divided suspended inorganic matters do not settle down so easily, so these smaller particles are converted into larger ones, which have higher settling velocities.

The commonly used coagulants are Al_2SO_4, Alum $[K_2SO_4(Al_2SO_4)_3 24H_2O]$, Ferrous Sulphate ($FeSO_4.7H_2O$), Sodium Aluminate ($NaAlO_2$). These coagulants react with water to form gelatinous precipitate in the form of hydroxides known as floc that absorbs the finely suspended and colloidal particles, which settle down rapidly. It is the most effective and economical means to remove impurities:

$$Al_2(SO_4)_3 + 6H_2O \longrightarrow 2Al(OH)_3 + 3H_2SO_4$$

$$NaAlO_3 + 2H_2O \longrightarrow NaOH + 2\,Al(OH)_3$$

In order to increase the efficiency of the coagulation process, coagulant aids such as lime, fullers earth, bentonite clay and polyelectrolyte are added. Coagulants are generally added in the solution form to the water with the help of mechanical flocculators provided with stationary or rotating baffles. It is necessary to ensure the thorough mixing of coagulant and raw water so that minimum coagulant dosage is required.

2.4.5 Filteration

In this method, suspended impurities,all types of insoluble colloidal and bacterial impurities are removed by passing water through a bed of proper-sized material through filtration process. Two types of filters are commonly used for filteration.

(A) Gravity Sand Filter

It consists of a large, rectangular tank made of concrete and a process medium, known as filter

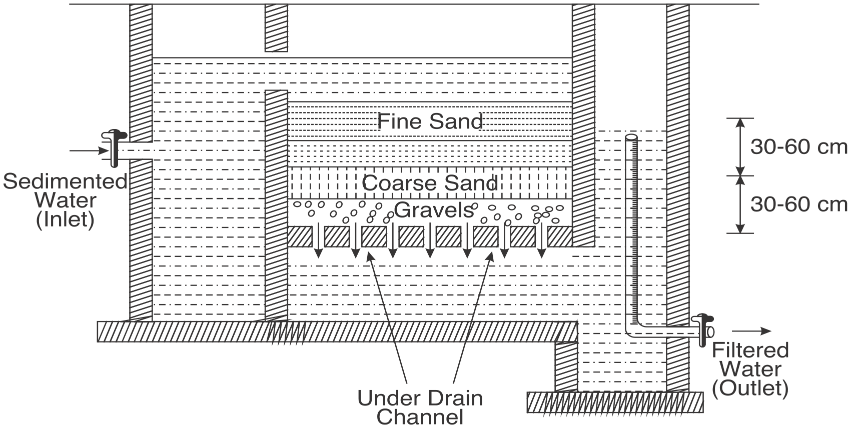


Fig. 2.14 Sand Filter

medium, which retains solid particles but allows the passage of water as shown in [Fig. 2.14]. It consists of three layers. The upper layer consists of fine sand (about 50 cm thick) and is a thick layer. The middle layer consists of coarse sand (about 20 cm thick), and the bottom layer consists of gravels (about 30 cm thick). It is provided with an inlet for sedimented water and an under drain channel at the bottom for the exit of filtered water. Sedimented water enters the sand filter from the top and is uniformly distributed over the fine sand layer.

As the water percolates through the sand bed, finely suspended particles and most of the germs and bacteria are retained by the top layer. Clear and filtered water is collected and is drawnout. The rate of filteration becomes slow after some time due to clogging of pores of the top sand layer by the impurities. Therefore, the portion of the top fine sand layer is scrapped or replaced by a new sand layer. This filter is put to use again.

(B) Pressure Filter

It consist of a cylindrical tank as shown in [Fig. 2.15]. Vertical steel tank is consisting of three layers of filtering media, one above the other. Pebbles layer (10–35 mm grain size) is placed at the bottom of the cylinder, coarse sand layer (5–7mm grain size) is placed at the middle and fine sand layer (1–2 mm grain size) is placed at the top of the cylinder tank.

Impure, sedimented water is mixed with a small amount of alum solution, and then water is forced through filter bed under pressure. Alum forms the slimy layer on the filter bed, and this helps in the removal of colloidal and bacteriological impurities. The function of deflector plate, which is provided at the top, is to distribute the slimy layer of alum uniformly over the top of the filter bed. Filtered water, as it comes out from the bottom of filter, is under pressure and can be pumped directly. These filters are widely used for industrial purposes.

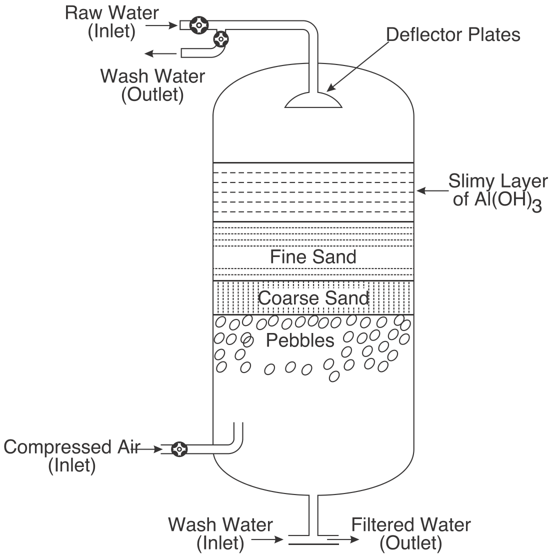


Fig. 2.15 Vertical Pressure Filter

SAQ 6	The finely divided suspended particles in water are removed by-			
	1. screening	2. sedimentation	3. coagulation	4. filteration

Key: 3

2.4.6 Disinfection/Sterilization

Sterilisation of water means complete destruction of all living microorganisms such as bacteria, virus, etc. present in the water. We know that water after passing through different processes such as sedimentation, coagulation, and filteration processes still contains a small percentage of pathogenic bacteria. Therefore, it is necessary to remove these bacteria and microorganisms from water. The chemicals used for sterilisation are known as sterilisers or disinfectants.

Several methods have been adopted for sterilisation of water. Some of them are given below:

Sterilisation Methods

Boiling | Chlorination | Ozonolysis | UV-rays | Membrane Technology

(A) Boiling Method

Water for domestic purposes may be sterilised by simple boiling method by boiling the water for about 20–30 min. This method kills the harmful disease-causing bacteria and germs. This process is very much expensive for municipal supply of water, and in addition, a large quantity of fuel is required to boil water on a large scale. It does not provide any protection for further contamination of water.

(B) Chlorination method

It is the most important method for sterilisation of water. Chlorination is done by using the following methods:

- Chlorine Gas or Concentrated Aqueous Solution.
- Bleaching Powder.
- Chloramine.

(i) Chlorine Gas or Concentrated Aqueous Solution

Chlorine is used directly as a gas or as chlorine water, is a powerful germicide and most commonly used disinfectant. It reacts with water to form hypochlorous acid and nascent oxygen, both of which are powerful germicides.

$$Cl_2 + H_2O \longrightarrow \underset{\text{Hypoclorous acid}}{HOCl} + HCl$$

$$HOCl \longrightarrow \underset{\text{Nascent Oxygen}}{[O]} + HCl$$

Apparatus

The apparatus used for disinfection by chlorine is known as chlorinator [Fig.2.16]. It is a large tower containing number of baffle plates. From the top of the tower, proper dose of chlorine and water is introduced. They get thoroughly mixed during their passage through the tower,and treated water is taken out from the bottom.

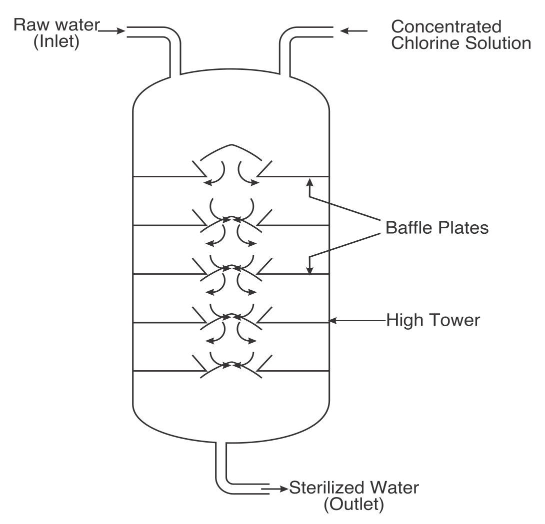


Fig. 2.16 Chlorinator

Advantages

- It is cheap, easily available disinfectant and effective at low concentration.
- It can be used at high and low temperatures.
- It is stable and does not deteriorate on keeping.
- Chlorine residue can be maintained in treated water, which provides additional safety for preventing regrowth of bacteria.

Disadvantages : Excess of chlorine produces an unpleasant taste and odour in water.

(ii) Bleaching Powder ($CaOCl_2$)

Bleaching powder is a strong oxidising agent and is having 30 percent available chlorine. When water is treated with bleaching powder, hypochlorous acid is formed. It releases nascent oxygen which deactivates the enzymes of micro-organisms and thus the metabolic activities will stop and the microorganisms will be killed.

$$CaOCl_2 + H_2O \longrightarrow Ca(OH)_2 + Cl_2$$

About 1 kg of bleaching powder is sufficient for 1000 kilo litres of water.

Disadvantages

- Excess of bleaching powder creates bad taste and odour to water.
- It introduces calcium hardness in water due to the formation of $Ca(OH)_2$
- It is unstable, hence its storage is difficult.

(iii) Chloramine (NH_2Cl)

By mixing of chlorine and ammonia in 2 : 1 ratio, chloramines is formed. Whenever water is treated with chloramines, hypoclorous acid is formed which protect it from recontamination.

Advantages

Excess dose of NH_2Cl does not create bad odour and taste in water.

Disadvantages

Excess of chlorine produces an unpleasant taste and odour in water.

(ii) Bleaching Powder ($CaOCl_2$)

Bleaching powder is a strong oxidising agent and is having 30 percent available chlorine. When water is treated with bleaching powder, hypochlorous acid is formed. It releases nascent oxygen which deactivates the enzymes of micro-organisms and thus the metabolic activities will stop and the microorganisms will be killed.

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About 1 kg of bleaching powder is sufficient for 1000 kilo litres of water.

Disadvantages

- Excess of bleaching powder creates bad taste and odour to water.
- It introduces calcium hardness in water due to the formation of $Ca(OH)_2$
- It is unstable, hence its storage is difficult.

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By mixing of chlorine and ammonia in 2 : 1 ratio, chloramines is formed. Whenever water is treated with chloramines, hypoclorous acid is formed which protect it from recontamination.

Advantages

Excess dose of NH_2Cl does not create bad odour and taste in water.

(C) Ozonolysis Method

Ozone is used for this method. Ozone is a highly unstable and excellent disinfectant. It breaks down and gives nascent oxygen which is very powerful oxidising agent and kills all the bacteria and germs present in water.

Apparatus

The reaction of ozone and water is carried out in ozone steriliser as shown in [Fig. 2.17]. During the treatment of water, water is allowed to enter from top to bottom, and ozone is allowed to enter from bottom to top, when they come in contact with each other it kills the germs. Sterilized water is collected at the bottom of the tank. The contact time for ozone and water is about 10–15 minutes.

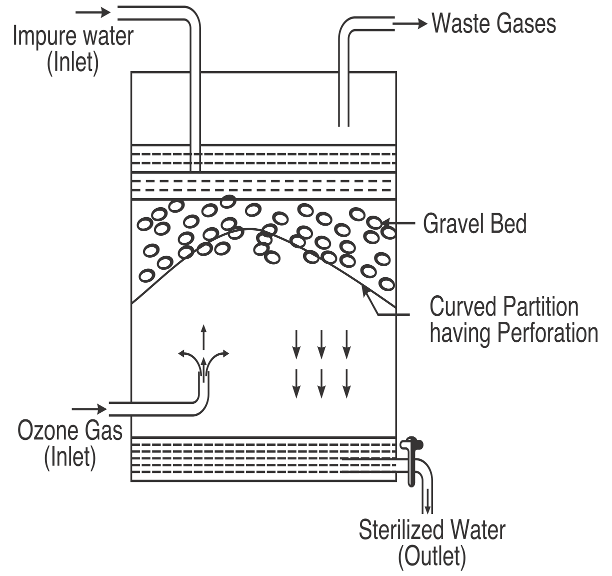


Fig.2.17 Ozonolysis Method

Advantages

- It removes colour and odour from water.
- It improves the taste of water.
- The excess dose of ozone is not harmful, because it releases oxygen on decomposition.

2.4.6 (D) UV-Rays Method

When water is exposed to UV-rays from electric mercury lamp that is immersed in water, most of the pathogenic bacteria are destroyed. This method is widely used for the disinfection of swimming pool water.

Advantages

- It does not require any chemicals.
- It does not produce any odour in water.

Disadvantages

It is very expensive, so it is not widely used on a large scale.

(E) Membrane Technology Method

Membrane filtration is a technique for testing water samples. In this procedure, water is drawn through a special porous membrane designed to trap microorganisms larger than 0.45 μm. Water is forced through membranes made of synthetic materials cellulose acetate, cellulose nitrate (collodion), polyamide (nylon), polycarbonate, polypropylene, and polytetrafluoroethylene (Teflon by the application of high pressure (in the range of 10 to 50 atm. pressure). Membrane processes are widely used for removal of bacteria, microorganisms, particulates, and natural organic material, which can impart colour, tastes, and odours to water and react with disinfectants to form disinfection by products. The four types of membrane filtration are known as reverse osmosis, nanofiltration, ultrafiltration and microfiltration, in order of increasing pore size.

Interesting fact : Climate change, increasing water scarcity, population growth, demographic changes and urbanization already pose challenges for water supply systems. By 2025, half of the world's population will be living in water-stressed areas.

2.5 INDIAN STANDARD SPECIFICATION OF DRINKING WATER

2.5.1 Introduction

Most of the human being cannot survive more than 3-4 days without water. Water is the primary necessity. Yet, it is a horrific fact that there are billions of people around the world who do not have access to clean drinking water. Safe and clean drinking water is important for public health. In 2010, the UN General Assembly explicitly recognised the human right to water and sanitation. Everyone has the right to sufficient, continuous, safe, acceptable, physically accessible, and affordable water for personal and domestic use.

The Indian Standard Drinking Water Specification (Second revision IS 10500:2012), was adopted by Bureau of Indian Standard (BIS) after the draft finalised by drinking water sectional committee had been approved by Food and Agriculture Division Council. Though spectrum of parameters are given by IS Specifications, but here the most important and widely tested parameters are mentioned. Organoleptic and Physical Parameters for Drinking Water, Parameters related to Bacteriological Quality of Drinking Water and General Parameters Concerning Substances Undesirable in Excessive Amounts for Drinking Water are given in table 2.6, table 2.7 and table 2.8 respectively.

Table 2.6 : Organoleptic and Physical Parameters for Drinking Water

S.No.	Characteristics	Requirement (Acceptable Limit)	Permissible Limit (in Absence of Alternate Source)
1.	Colour, Hazen units, Max	5	15
2.	Odour	Agreeable	Agreeable
3.	pH value	6.5-8.5	No relaxation
4.	Taste	Agreeable	Agreeable
5.	Turbidity, NTU,Max	1	5
6.	Total dissolved solids, mg/l, Max	500	2000

NOTE : It is recommended that the acceptable limit is to be implemented. Values of characteristics in excess of those mentioned under acceptable limit render the water unsuitable, but still may be tolerated in the absence of an alternative source only up to the limits indicated under 'permissible limits, In the absence of alternate source, above which the sources will have to be rejected.

Table 2.7 Bacteriological Quality of Drinking Water

S.No.	Organisms	Requirements
1.	For All water intended for drinking: E. coli or thermotolerant coli form bacteria	Should not be detectable in any 100mL sample
2.	Treated water either in the distribution system or entering the distribution system: a) E. Coli or thermotolerant coli form bacteria b) Total coli form bacteria	Should not be detectable in any 100mL sample Should not be detectable in any 100mL sample

Immediate investigative action shall be taken if either E.coli or total coliform bacteria are detected. The minimum action in the case of total coliform bacteria is repeat sampling. if these bacteria are detected in the repeat sample, the cause shall be determined by immediate further investigation

Total coliform bacteria are not acceptable indicators of the sanitary quality of rural water supplies, particularly in tropical areas where many bacteria of no sanitary significance occur in almost all untreated supplies.

Table 2.8 General Parameters Concerning Substances Undesirable in Excessive Amounts

S.No.	Characteristics	Requirement (Acceptable Limit)	Permissible Limit (in Absence of Alternate Source)
1	Aluminium(asAl),mg/L,Max	0.03	0.2
2.	Ammonia (as total ammonia-N), mg/L,Max	0.5	No relaxation
3.	Anionic detergents (as MBAS) mg/L,Max	0.2	1.0
4.	Calcium(as Ca),mg/l,Max	75	200
5.	Chloramines (as Cl_2),mg/l,Max	4.0	No relaxation
6.	Chloride(as Cl),mg/L,Max	250	1000
7.	Copper(as Cu),mg/L,Max	0.05	1.5
8.	Fluoride(as F)mg/L,Max	1.0	1.5
9.	Free residual chlorine, mg/L,Min	0.2	1
10.	Iron(as Fe),mg/L,Max	0.3	No relaxation
11.	Magnesium(as Mg),mg/L,Max	30	100
12.	Manganese(as Mn),mg/L,Max	0.1	0.3
13.	Mineral oil, mg/L,Max	0.5	No relaxation
14.	Nitrate(as NO_3),mg/L,Max	45	No relaxation
15.	Phenolic compounds (as C_6H_5OH),mg/L,Max	0.001	0.002

S.No.	Characteristics	Requirement (Acceptable Limit)	Permissible Limit (in Absence of Alternate Source)
16.	Sulphate (as SO_4) mg/L, Max	200	400
17.	Sulphide (as H_2S), mg/L, Max	0.05	No relaxation
18.	Total alkalinity as calcium carbonate,mg/L,Max	200	600
19.	Total hardness (as $CaCO_3$), mg/L,Max	200	600
20.	Zinc (as Zn),mg/L,Max	5	15

NOTE : Values in excess of those mentioned under 'acceptable limit' render the water unsuitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible, above which the sources will have to be rejected.

SAQ-7	As per the IS specification of drinking water, the acceptable limit of flouride in mg/L water is			
	1. 1.0	2. 1.5	3. 0.5	4. 2.0

Key : 1

2.6 WATER FOR HUMAN CONSUMPTION FOR DRINKING AND COOKING PURPOSES FROM ANY WATER SOURCES

Interesting Fact : In India about 53% of households rely on groundwater resources for potable water need while about 2% rely on surface water. About 43.5% of households access tap water (treated + untreated) for potable purposes

Water covers two thirds of the earth's surface, most of it is salty and not suitable for drinking purpose. Only 3% of the available water on earth is freshwater and only 1 percent of the available freshwater can be accessed for use from rivers, lakes and groundwater. About 97% of the water on the earth's surface is covered with sea water. The details of the distribution of water had already been explained in previous section. The three main sources of water are:

- Groundwater – This includes water bodies like borewells, tubewells, dugwells, handpumps and springs.
- Surface water – This includes different water bodies like sea, oceans, reservoirs, rivers, streams, ponds, lakes and tanks.
- Rainwater.

India's total annual utilisable water resources is 1123 billion cubic metres (690 bcm surface water + 433bcm ground water). Drinking water in India is mostly derived from groundwater. Rivers and wells are also major sources of water which are used by municipalities. The data shows that groundwater is the most reliable source of drinking water for nearly 43 percent of the rural population in the country (National Sample Survey Office's (NSSO) data).

Groundwater is an important source for domestic usage. It is also a major source of drinking water in urban and rural India. 80% of domestic water comes from ground water reserve. The main source of ground water is the recharge from monsoon precipitation. About 58% of countries annual rechargeable ground water is contributed by monsoon rainfall. Other sources of recharge viz. seepage from canals, tanks, ponds and other water structures and irrigation account for about 32%. Although India receives plenty of water as rainfall during monsoon but due to lack of storage, only a small percentage of that water is actually added to the reserve. There is significant mismatch of spatial distribution of available water with the population, the situation becomes alarming; ironically less water is available where more people live.

Surface water sources such as rivers and wells are the major source of water ,used by municipalities for public use . Studies by the Central Water Commission (2015) also show that surface drinking water source rivers in India are loaded with toxic heavy metals such as lead, arsenic, copper, cadmium, mercury and nickel that are highly toxic and carcinogenic and are beyond the standard limits prescribed by Indian Council of Medical Research (ICMR) and Bureau of Indian Standards (BIS).

Ensuring safe water supply and sanitation is a state responsibility under the Indian Constitution.

SOLVED PROBLEMS

Q.2.1 A sample of hard water has a hardness of 450 ppm. Express the hardness in ^{0}French and ^{0}Clark.

Sol. **Hint :** Refer table 2.2

1 ppm = 0.07 ^{0}Cl

450 ppm = 450 × 0.070Cl

450 ppm = 31.5 ^{0}Cl

Q.2.2 10 litre of water had salt equivalent 2.4mg of $CaCO_3$. Find the hardness of the water in
i) mg/litre ii) ppm iii) ^{0}Fr iv) ^{0}Cl

Sol. **Hint :** Refer table 2.2

i) mg/litre = (1 parts of $CaCO_3$) / (litre of water)

= (2.4 ×1000)/10

= (2.4 ×1000)/10

= 240 mg/litre

The hardness of water is 240 mg/litre

ii) ppm

1mg/L = 1 ppm

240 mg/L = 240 ppm The hardness of water is 240 ppm

iii) 1mg/L=0.1^{0}Fr

240 mg/L = 24 ^{0}Fr The hardness of water is 24 ^{0}Fr

iv) 1mg/L = 0.07 ^{0}Cl

240 mg/L = 240 × 0.07 The Hardness of water is 16.8 ^{0}Cl

Q. 2.3 A sample of water gives following data

$MgCl_2$ = 1.43 ^{0}Fr SiO_2= 1.43 ^{0}Fr $MgSO_4$ = 5.72 ^{0}Fr
$CaSO_4$ = 2.86 ^{0}Fr $Ca(HCO_3)_2$ =23.16 ^{0}Fr
Calculate the hardness in ^{0}Cl and ppm scale.

Sol. **Hint :** Refer table 2.2

First of all we have to convert present salts in ^{0}Cl and ^{0}Fr

Name of Salt	1^{0}Fr	1^{0}Fr= 0.7 Cl	1^{0}Fr=10 ppm
$MgCl_2$	1.43	0.7 × 1.43 = 1.001 ^{0}Cl	1.43 × 10 = 14.3 ppm
$MgSO_4$	5.72	0.7 × 5.72 = 4.004 ^{0}Cl	5.72 × 10 = 57.2 ppm
$CaSO_4$	2.86	0.7 × 2.86 = 2.002 ^{0}Cl	2.86 × 10 = 28.6 ppm
$Ca(HCO_3)_2$	23.16	0.7 × 23.16 = 16.212 ^{0}Cl	23.16 × 10 = 231.6 ppm

The hardness of $CaCO_3$ equivalent can be expressed taking into consideration equivalent weight of compound i.e. 50/E

where 50 - equivalent weight of $CaCO_3$

E - equivalent weight of $CaCO_3$

Hardness of present Compounds in terms of $CaCO_3$ equivalent

Name of Salt	Equivalent Weight	^{0}Cl	ppm
$MgCl_2$	47.5	(1.001× 50)/47.5	(14.3 × 50)/47.5
$MgSO_4$	60	(4.004 × 50)/60	(57.2 × 50)/60
$CaSO_4$	68	(2.002 × 50)/68	(28.6 × 50)/68
$Ca(HCO_3)_2$	81	(16.212 × 50)/81	(231.6 × 50)/81

Total Hardness is the sum of the hardness of all compounds

Total Hardness = Hardness of [$MgCl_2$ +$MgSO_4$+$CaSO_4$+$Ca(HCO_3)_2$]

Total hardness in ^{0}Cl can be calculated as

Total Hardness = (1.001× 50)/47.5+(4.004 × 50)/60+(2.002 × 50)/68+(16.212 × 50)/81

= 50 [1.001/47.5+4.004/60+2.002/68+16.212/81]

Total Hardness = 50[0.0210+0.0667+0.0294+0.2001]=50[0.3172]=**15.86 ^{0}Cl**

Total hardness in ^{0}Fr can be calculated as

Total Hardness = (14.3×50)/47.5+(57.2×50)/60+(28.6×50)/68+(231.6×50)/81

= 50[14.3/47.5+(57.2)/60+(28.6)/68+(231.6)/81]

= 50 [0.3010 + 0.9533 +0.4205 + 2.8592]

= 50[4.5327]

= **226.635 ppm**

Q. 2.4 100ml of water sample had Temporary hardness =160mg/L Total hardness =245mg/L Find the permanent hardness in the water sample.

Sol. Total Hardness = Temporary Hardness + Permanent Hardness

245mg/L =160 mg/L + Permanent Hardness

Permanent Hardness =245 – 160 = 85 mg/L

1000 ml of water sample = 85 mg/L of hardness

100 ml of water sample show = ?

=(85 ×100)/1000=8.5 mg/L

Hence, permanent hardness in the 100ml sample =8.5mg

Q.2.5 Write the reaction involved in disinfection of water using bleaching powder.

Key:

$$CaOCl_2 + H_2O \longrightarrow Ca(OH)_2 + Cl_2$$

$$Cl_2 + H_2O \longrightarrow \underset{\text{Hypoclorous acid}}{HOCl} + HCl$$

$$HOCl \longrightarrow \underset{\text{Nascent Oxygen}}{[O]} + HCl$$

UNIT SUMMARY

- **Soft Water:** Water that produces lather easily on shaking with soap solution is called soft water.
- **Hard Water:** Water that does not produce lather with soap solution readily but forms a white curd i.e. white scum is called hard water.
- **Temporary Hardness:** Hardness of water that can be removed by mere boiling is known as temporary hardness.
- **Permanent Hardness:** A hardness that cannot be removed by mere boiling is known as permanent hardness.
- **Parts Per million (ppm):** The number of parts by weight of calcium carbonate present per million parts by weight of water.
- **French Degree of Hardness (^{0}Fr):** Number of parts by weight of $CaCO_3$ present in 100000 (or 10^5) parts by weight of water.
- **Degree Clark (^{0}Cl):** Number of parts by weight of calcium carbonate in 70000 parts by weight of water.
- **Milligrams per litre (mg/litre):** Number of milligrams of $CaCO_3$ equivalent hardness present per litre of water.
- **Milliequivalent per litre (meq/L):** Number of milliequivalent of hardness is present per litre.
- **Sludge:** Loose, slimy precipitate deposits are formed inside the boiler and do not stick up permanently are known as Sludges.
- **Scale:** Hard adhering coating on the inner surface of the boiler are known as scale.
- **Priming:** When the boiler is being steamed rapidly, some liquid water particles are mixed with the steam. This process of wet steam formation is called priming.
- **Foaming:** Foaming is the production of persistent foam or bubbles in boilers that do not break easily. Foaming is due to the presence of substance like oils.
- Water softening methods used for treatment of hard water are SodaLime Process, Zeolite Process and Ion Exchange process.
- In Soda Lime Process, lime (CaO) or hydrated lime ($Ca(OH)_2$) and soda ash (Na_2CO_3) are used for precipitation process of softening.
- In Zeolite Process or Permutit Process, softening of water is done by natural or artificial zeolite. Zeolite is hydrated sodium alumin silicate. Zeolites are substances that are insoluble in water and can act as base exchanger when placed in contact with water containing cations.

- In an ion exchanges process, a reversible exchange of ions take place between the stationary ion-exchange phase and the mobile external liquid phase. Ion exchange resins are insoluble, cross linked, long chain organic polymers with a microporous structure and the functional groups attached to them are responsible for ion exchanging properties
- The different methods employed for treatment of water for municipal supply are

  Screening : Removes the floating materials like leaves.

  Sedimentation : Removes suspended impurities like sand, clay, etc.

  Coagulation : Removes finely divided suspended particles.

  Filteration : Removes colloidal impurities and large organisms.

  Disinfection : Kills the bacteria.

EXERCISES

2.1 Differentiate between soft and hard water on the three most important points.

2.2 List the different units of hardness.

2.3 Give reasons for poor leathering of soap in hard water.

2.4 Differentiate between scale and sludge formation with the help of diagram.

2.5 Mention the causes of corrosion in boiler.

2.6 Explain the quantitative determination of water by EDTA method.

2.7 Explain the quantitative determination of water by alkalinity method.

2.8 Classify the external and internal methods of treatment of hard water.

2.9 Describe the softening of water using zeolite process. Write advantages and limitations of the same.

2.10 Compare between zeolite process and soda-lime process of softening of water.

2.11 Classify the types of ion exchangers on the basis of functional group.

2.12 Explain briefly the different methods employed for purification of water for potable use, based on the types of impurities present.

2.13 Write regeneration reactions for ion exchangers.

2.14 Write the IS specification of drinking water on the following parameters
i) Ca ii)Fluoride iii) Copper iv) Fe v) Mg vi) Sulphate

vii) total alkalinity viii) total hardness ix) Zn

PRACTICALS

1. HARDNESS OF WATER

PRACTICAL STATEMENT

Estimate the total hardness of given water sample using standard ethylene diamine tetra acetic acid (EDTA) solution

PRACTICAL SIGNIFICANCE

Boilers are important equipment for various industrial process so as to produce steam using water. Amount of impurities present in water plays a vital role in terms of efficiency of boiler and various problems caused by boiler. Water is used in different industries for various industrial operations. Diploma engineer has to deal with different usage of water during their work and also deals with the problems caused by hard water like corrosion, scale and sludge formation.

RELEVANT THEORY

Refer this unit 2, section 2.2.3

PRACTICAL OUTCOMES (PrOs)

PrO1 Weigh accurately the given sample in electronic balance.
PrO2 Prepare standard solution of given sample of defined molarity and normality.
PrO3 Calculate temporary, permanent and total hardness of water

CHEMICALS/ GLASSWARE REQUIRED

- **Chemicals (AR Grade)** Water sample, EDTA (0.1M), Buffer solution (pH=10), Eriochrome Black T(EBT) indicator,
- **Glasswares (Borosil)** Conical flask(100 ml), Burette(50 ml), pipette(10 ml), beaker (100 ml, 250 ml)

SAFETY PRECAUTIONS

1. Use mask, gloves and apron while working in the lab.
2. Handle the glasswares and chemicals carefully
3. All glassware should be washed with distilled water before use.
4. Remove air gap from lower part of nozzle and adjust lower meniscus to zero mark.
5. Use white tile during titration to observe the colour change.

SUGGESTED PROCEDURE

Part A: Total Hardness of water

1. Rinse and fill the burette with 0.01M EDTA solution.
2. Pipette out 10ml of water sample in conical flask.
3. Add 5ml of buffer solution(pH=10) and 2-3 drops of EBT indicator in the conical flask.
4. Due to addition of EBT, mixture in conical flask shows wine red colouration.
5. Titrate the solution in conical flask with EDTA till colour changes from wine red to light blue.
6. Repeat the procedure for three consequent burette reading.

Part B: Permanent Hardness of Water

1. Boil the given sample for 8-10 minutes and filter.
2. Pipette out 10 mL of filtered water in conical flask.
3. Follow the procedure as per part A

OBSERVATIONS AND CALCULATIONS

1. Solution in burette :…………………………
2. Solution in conical flask:……………………
3. Indicator:…………………………………………
4. End Point : ………………………………………..

Part A: Total Hardness of Water

Readings	Pilot Reading	1	2	3	TH=Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)					
Final Burette Reading (FBR)					
Difference (FBR-IBR)					

Part B: Permanent Hardness of Water

Readings	Pilot Reading	1	2	3	PH = Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)					
Final Burette Reading (FBR)					
Difference (FBR-IBR)					

Part A : Total Hardness of water

Step 1 :

1000mL of 1M EDTA $\equiv$ 100 g $CaCO_3$

(TH) mL of 0.01M EDTA $\equiv \frac{100 \times 0.01 \times TH}{1000}$ g of $CaCO_3$ = 0.001 × TH g of $CaCO_3$

$\equiv$ 0.001 × TH =0.001×……………….=……………..(y)g of $CaCO_3$

Step 2:

10ml of water sample contains (y) g of $CaCO_3$
1000ml of water sample contains =100×(y)g of $CaCO_3$ =…………g of $CaCO_3$
Conversion of g to mg
1000mL of water sample contains = 100×(y) g of $CaCO_3$ ×1000 mg of $CaCO_3$
1000mL of water sample contains =…………………… mg of $CaCO_3$ ---- **(I)**

Part B: Permanent Hardness (PH) of Water

Step 1 :

1000mL of 1M EDTA $\equiv$ 100 g $CaCO_3$

(PH) mL of 0.01M EDTA $\equiv \frac{100 \times 0.01 \times PH}{1000}$ g of $CaCO_3$= 0.001 × PH g of $CaCO_3$

$\equiv$ 0.001 ×PH =0.001×………………=………………(z)g of CaCO3

Step 2 :

10 mL of water sample contains (z) g of $CaCO_3$

1000 mL of water sample contains = 100 × (z)g of $CaCO_3$ =…………g of $CaCO_3$

Conversion of g to mg

1000 mL of water sample contains = 100×(z) g of $CaCO_3$ ×1000mg of $CaCO_3$

1000 mL of water sample contains =……………………mg of $CaCO_3$ ---- **(II)**

Temporary hardness = Total Hardness - permanent hardness of water in mg of $CaCO_3$
= I – II = ……….
= …………………… mg of $CaCO_3$

RESULTS AND/OR INTERPRETATION

1. Total Hardness for given sample of water is = …………………ppm of $CaCO_3$ equivalent
2. Permanent Hardness for given sample of water is =………….. ppm of $CaCO_3$ equivalent
3. Temporary Hardness for given sample of water is =………….. ppm of $CaCO_3$ equivalent

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Write the reaction between Ca ion and Mg ion and EDTA with hard water
2. State the role of buffer solution in the given titration.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin) ♻	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH : REUSE, REDUCE & RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.

2 While performing this experiment, use the desired amount of substance to reduce the waste.

3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name…………………………...........………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	% Weightage	Marks Obtained	Product Indicators (30%)	% Weightage	Marks Obtained	
Accuracy in weighing of sample	10		Viva-voce	10		
Preparation of solution and titration	30		Report preparation	10		
Housekeeping	10		Calculations,results and interpretation	10		
Handling of glasswares	10					
Observance/ follow safety precautions	10					

2. ALKALINITY OF WATER

PRACTICAL STATEMENT

Determine the alkalinity of a given water sample using 0.01M sulphuric acid.

PRACTICAL SIGNIFICANCE

Water plays a vital role in variety of industrial processes. This experiment helps diploma engineers to determine the scale and type of alkalinity to control corrosion. Alkalinity is important for aquatic life as it protects or buffers against rapid pH changes. It is important factor in treatment of waste water and drinking water because it influences cleaning process such as anaerobic digestion. Alkalinity is a measure of how much acid can be added to a liquid without causing a large change in pH.

RELEVANT THEORY

Base and alkali neutralize acid showing pH>7. Base does not dissolves in water but alkali dissolves in water. (Refer Unit 2,section 2.2.4)

PRACTICAL OUTCOMES (PrOs)

PrO1 Weigh accurately the given sample in electronic balance.

PrO2 Prepare standard solution of given sample of defined molarity and normality.

PrO3 Find alkalinity due to OH^-, CO_3^{2-}, HCO_3^-

CHEMICALS/ GLASSWARE REQUIRED

- **Chemicals (AR Grade)** Standard sulphuric acid, phenolphthalein indicator, methyl orange, ethyl alcohol, distilled water.
- **Glasswares (Borosil)** Burette, pipette, conical flask (250mL), standard flask, measuring cylinder

SAFETY PRECAUTIONS

1. Do not keep the indicator open since it contains alcohol which tends to evaporate.
2. While handling chemicals and indicators, care should be taken so that it does not spill on your skin.

SUGGESTED PROCEDURE

Preparation of 0.01 N Sulphuric acid Solution

1. Take approximately 500ml distilled water in a 1000 mL standard flask.
2. Measure 200mL of 0.1N sulphuric acid and add slowly along the side of the standard flask.
3. Then dilute up to 1000ml using distilled water hence we get 0.02N sulphuric acid.

Preparation of Phenolphthalein Indicator

1. Weigh out 1g of phenolphthalein powder and add 100 mL of ethyl alcohol or water
2. Use a ready-made phenolphthalein indicator.

Titration Procedure

i. Rinse and fill the 0.01N sulphuric acid into the burette.

ii. Measure exactly 100mL of sample and transfer it into 250mL conical flask.

iii. Add few drops of phenolphthalein indicator into the conical flask which shows pink colouration which indicates the presence of alkalinity due to hydroxyl ions.

iv. Titrate this against 0.01 N Sulphuric acid till the pink colour disappears which shows neutralization of hydroxyl ions. Record this burette reading which is accountable for phenolphthalein alkalinity.

v. To the same colourless solution in the conical flask add few drops of methyl orange indicator. The colour of the solution changes to yellow which is due to the presence of CO_3^{2-} and HCO_3^- ions in the water sample.

vi. Continue the titration from the point where stopped for the phenolphthalein alkalinity.

vii. Titrate till the solution becomes reddish orange.

viii. The entire volume V_2 of sulphuric acid is noted down and it is accountable for calculating methyl orange alkalinity.

ix. Repeat the procedure for consecutive readings.

OBSERVATIONS AND CALCULATIONS

Observations

The solution in burette ……………………..

Indicator …………………………………..............

End point…………………………………………

Observation Table 1: Phenolphthalein alkalinity

Readings	Pilot Reading	1	2	3	P=Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)					
Final Burette Reading (FBR)					
Difference (FBR-IBR)					

Observation Table 1: Total alkalinity

Readings	Pilot Reading	1	2	3	M=Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)					
Final Burette Reading (FBR)					
Difference (FBR-IBR)					

Calculations

For alkalinity refer this unit 2 section 2.2.3

(i) Alkalinity due to OH^- (if P=M)

Step 1 :

1000 mL of 1N H_2SO_4 = 17 g OH^-

M ml of 0.01N H_2SO_4 = $\frac{17 \times 0.01 \times M}{1000}$ g of OH^-= $\frac{17 \times 0.01 \times \ldots}{1000}$ =……(x)g of OH^-

Step 2 :

100mL of water sample contains =(x) g =…………………… g of OH^-

1000mL of water sample contains =(x)×10 =…………………… g of OH^-

1000mL water sample contains = (x) ×10×1000 = …………………… mg of OH^-

1000mL water sample contains =…………………… mg of OH^-

(ii) Alkalinity due to CO_3^{2-}(if p<(1)/2M)

Step 1:

1000 mL of 1N H_2SO_4 = 30g CO_3^{2-}

[2P-M] mL of 0.01N H_2SO_4 = $\frac{30 \times 0.01 \times [2P-M]}{1000}$ g of CO_3^{2-}

= $\frac{30 \times 0.01 \times \ldots}{1000}$ = …………………… (y)g of CO_3^{2-}

Step 2 :

100mL of water sample contains =(y) g = …………………… g of CO_3^{2-}
1000mL of water sample contains =(y)×10 = …………………… g of CO_3^{2-}
1000mL water sample contains = (y) ×10×1000 = …………………… mg of CO_3^{2-}
1000mL water sample contains = …………………… mg of CO_3^{2-}

(iii) Alkalinity due to HCO_3^- (if $p < \frac{1}{2M}$)

Step 1 :

1000 mL of 1N H_2SO_4 = 61g HCO_3^-

$$[2P\text{-}M] \text{ mL of } 0.01N\ H_2SO_4 = \frac{61 \times 0.01 \times [2P - M]}{1000} \text{ g of } HCO_3^-$$

$$= \frac{61 \times 0.01 \times \ldots\ldots}{1000} = \ldots\ldots\ldots\ldots(z)\text{g of } HCO_3^-$$

Step 2 :

100 mL of water sample contains =(z) g =…………………… g of HCO_3^-
1000 mL of water sample contains =(z)×10 =…………………… g of HCO_3^-
1000 mL water sample contains= (z) ×10×1000 = …………………… mg of HCO_3^-
1000 mL water sample contains =…………………… mg of HCO_3^-

RESULTS AND/OR INTERPRETATION

1. Alkalinity due to OH^- =…………………… mg/L
2. Alkalinity due to CO_3^{2-} =…………………… mg/L
3. Alkalinity due to HCO_3^- =…………………… mg/L

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce

1. Explain the ill effects of alkaline water on boilers
2. Mention the pH of pure natural water

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH : REUSE, REDUCE & RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

Chemical parameters of water

SUGGESTED LEARNING RESOURCES

https://vlab.amrita.edu/?sub=2&brch=193&sim=1548&cnt=1

SUGGESTED ASSESSMENTSCHEME

Name of the Student ………………………………………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Accuracy in weighing of sample	10		Viva-voce	10		
Preparation of solution and titration	30		Report preparation	10		
Housekeeping	10		Calculations,results and interpretation	10		
Handling of glasswares	10					
Observance/ follow safety precautions	10					

KNOW MORE

- **Chemical Oxygen Demand :** Chemical Oxygen Demand (COD) is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite.
- **Biological Oxygen Demand :** Biochemical Oxygen Demand (BOD) is the amount of dissolved oxygen (DO) needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at a certain temperature over a specific period.

- **Calgon :** Calgon is sodium hexa meta phosphate which is added to boiler or in washing machine water to prevent lime scale formation.
- **Flocculation :** Flocculation, in the field of chemistry, is a process by which colloidal particles come out of suspension to sediment under the form of floc or flake, either spontaneously or due to the addition of a clarifying agent.
- **Difference between Coagulation and Flocculation :** Flocculation is synonymous with agglomeration and coagulation / coalescence. Basically, coagulation is a process of addition of coagulant to destabilise a stabilised charged particle. Meanwhile, flocculation is a mixing technique that promotes agglomeration and assists in the settling.

Suggestive Micro Projects / Activities

- Collect water samples from different water sources and measure the hardness of water.
- Collect the water sample from different sources of ground and surface water (atleast five). Explore the new and simplest softening and water treatment methods and perform the same at your home by creating the different assemblies and manipulative techniques at home. Determine the turbidity and pH of water (using pH paper).
- Suppose you have been selected at top diploma engineering college at metro city. You have been living there for more than three months. Based on your critical observation and experiencing on the different kind of activities/ performances, identify the type of water being used by you. Draw your inferences on the same

Inquisitiveness and Curiosity

We are fortunately blessed with abundant rainfall. Rain being the purest form of natural water, why we are not able to conserve this water . We need to try different strategies and explore more on rain water harvesting

REFERENCES AND SUGGESTED READINGS

- C.N.R.Rao, UnderstandingChemistry, Universities Press (India) Pvt. Ltd.,2011, ISBN 8173712506
- Dara, S. S. & Dr. S. S. Umare, Engineering Chemistry, Universities Press (India) Pvt.Ltd., 2011, ISBN, 8121903599
- Jain & Jain, Engineering Chemistry, Dhanpat RaiandSons; New Delhi, 2015, ISBN 8187433175
- Shikha Agarwal, Engineering Chemistry, Cambridge University Press; New Delhi,2015. ISBN, 978-1-107-47641-7
- Text Book of Chemistry for Class XI & XII (Part-I, Part-II), N.C.E. R.T., Delhi, 2017-18.
- Indian Standard “Drinking Water Specifiction (Second Revision), IS10500:2012

3

Engineering Materials

UNIT SPECIFICS

This unit comprises of the following major topics:

- Natural Occurrence of Metal
- General Chemical Composition, Composition Based Applications
- Polymers

The different concepts have been explained through examples for generating further curiosity and inquisitiveness and also developing creative problem solving abilities in the students, with the mention of their practical applications in the industries/day to day life.

Assessment for learning at different intervals within the unit, at different levels of cognitive domain is carried out by designing formative assessment questions.

For effective implementation of the outcome based curriculum in true spirit, wide spectrum of activities such as micro projects, assignments, industrial visits etc, are designed and integrated in the unit for the benefit and exposure of the students. Sample QR codes have been provided on various topics/sub topics for supplementary reading and reinforcing the learning. \

RATIONALE

Elements are the basic units of all types of matter in the universe. It is important to understand that how do these elements occur in the earth's crust, atmosphere and sea. These elements may be classified into metals, non-metals and metalloids. 80% of earth crust is a great source of metals. Some soluble metal salts are found in the sea water also. 80% of the elements are metals. Each class of engineering materials like cement, glasses, refractory, plastics and rubber has its distinct characteristics and show wide range of applications in variety of fields.

In this unit we will be learning about extraction/isolation and purification of metals along with composition and application and of engineering materials used in variety of industries.

PRE-REQUISITES

Chemistry : Composition of matter

Mathematics : Basic algebra and geometry

UNIT OUTCOMES

List of outcomes of this unit are as follows :

U3 - O1 :	Select appropriate metallurgical processes for concentration, extraction and purification of the given ore.
U3 - O2 :	Write the composition, properties and uses of ferrous and non-ferrous alloys.
U3 - O3 :	Differentiate among the different engineering materials based on their chemical composition and composition based applications.

Unit - 3 Outcomes	Expected Mapping of Unit Outcomes with the Course Outcomes (1- Weak Correlation; 2- Medium Correlation; 3- Strong Correlation)				
	CO-1	CO-2	CO-3	CO-4	CO-5
U3-O1	-	-	3	1	1
U3-O2	-	-	3	-	-
U3-O3	1	-	3	-	-

3.1 INTRODUCTION TO NATURAL OCCURRENCE OF METALS

Earth crust is a great source of metals. These metals are found to occur in nature in two states, either in the free state (native state) or in the combined state, in the form of their compounds (with other elements).

(i) Native State or Free State

A metal is said to occur in a free state when it is found in the crust of the earth in the elementary or uncombined form. These are unreactive and have no tendency to react with oxygen and are not attacked by moisture, carbon dioxide of air or other non-metals. Only a few less reactive metals like copper, silver, gold and platinum are found in the free state as metals because of their low chemical reactivity. It is important to note that copper and silver metals occur in free state as well in the combined state.

(ii) Combined State

Most metals are found to occur in a combined state in the form of its compounds. This is due to the reaction of metals with moisture, air and other substance present in the earth surface under high temperature and pressure. These compounds are called minerals and ores.

3.1.1 Minerals and Ores

Minerals

The naturally occurring chemical substances in which metals or their compounds occur either in native state or combined state are called **minerals.**

The place where these minerals are found is called mine. Some minerals may contain large percentage of metal whereas others may contain small percentage of metal. Some minerals may not contain any objectionable impurities whereas others may contain objectionable impurities which hamper the extraction. Thus all the minerals cannot be used to extract metals.

Example : Aluminium occurs in the earth crust in the form of two minerals, bauxite ($Al_2O_3.2H_2O$) and clay ($Al_2O_3.2SiO_2.2H_2O$). Out of these two, aluminium can be conveniently and economically extracted from bauxite so bauxite is an ore of aluminium.

Table 3.1 Difference between Minerals and Ore

Minerals	Ores
All the naturally occurring substances that are present in the earth's crust are known as Minerals.	Ores are usually used to extract metals economically. A large number of metals are present.
All minerals are not ores.	All ores are minerals.
Minerals are native forms in which metals exist.	Ores are mineral deposits.

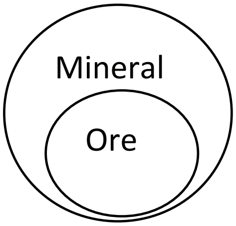


Fig. 3.1. Ore and Mineral

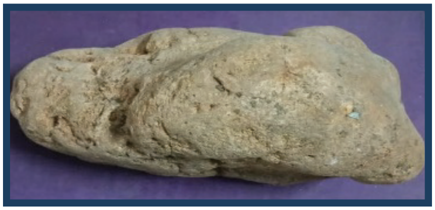


Fig. 3.2 An Ore

Ores and Minerals

Ores

Those minerals from which the metals are extracted easily and economically are called **ores.**

An ore contains a good percentage of metal and there are no objectionable impurities. Thus, all the ores are minerals, but all the minerals are not ores. [Fig. 3.1]. The ores generally contain unwanted impurities such as sand, stone, earthy particles, limestone, mica. These are called gangue or matrix. You can have a look of ore in [Fig.3.2]. The difference between minerals and ores is given in table 3.1.

Types of Ores

The most common ores of metals are oxides, sulphides, carbonates, halides etc.

(a) Metals which are only slightly reactive occur as sulphides (CuS, PbS etc.)

(b) Reactive metals occur as oxides (MnO_2, Al_2O_3 etc.)

(c) Most reactive metals occur as salts as carbonates, sulphates, halides etc. (Ca, Mg, K etc.)

(A) Ores of Iron, Aluminium and Copper

Ores of iron, aluminium and copper are given below in table 3.2

Table 3.2 Ores of Iron, Aluminium and Copper

S.No.	Ores of Iron		Ores of Aluminium		Ores of Copper	
1.	Haematite	Fe_2O_3	Bauxite	$Al_2O_3.2H_2O$	Copper Glance	Cu_2S

S.No.	Ores of Iron		Ores of Aluminium		Ores of Copper	
2.	Magnetite	Fe_3O_4	Cryolite	Na_3AlF_6	Copper Pyrites	$CuFeS_2$
3.	Lemonite	$Fe_2O_3.3H_2O$	Diaspore	$Al_2O_3H_2O$	Cuprite or Ruby copper	Cu_2O
4.	Iron Pyrites	FeS_2	Corundum	Al_2O_3	Malachite Green	$Cu(OH)_2CuCO_3$
5.	Siderite	$FeCO_3$	Alunite	$K_2SO_4Al_2(SO_4)_34Al(OH)_3$	Azurite	$Cu(OH)_2.2CuCO_3$
			Mica	$K_2O_3Al_2O_36SiO_32H_2O$	Dolomite	$CuCO_3MgCO_3$
			Feldspar	$K_2O.Al_2O_3.6SiO_2$		

3.1.2 General Principles of Metallurgy

After mining the ore from the ground, it needs to be converted into pure metal. To obtain a metal from its ore is called extraction of metal. The process of extracting metals from their ores and then refining them for use is called metallurgy. The process of metallurgy depends upon the nature of metal and type of impurities present. There is not a single method for the extraction of all metals. However, most of the metals can be extracted by a general principles and procedure which involves the following steps.

Various steps involved in metallurgical processes are -

- Crushing and grinding of the ore
- Concentration of the ore or enrichment of the ore
- Extraction of metal from the concentrated ore
- Refining or purification of the impure metal

(A) Crushing and Grinding of Ore

Most of the ore occur as big rock in nature. After digging out the ore from mines, it is crushed into small pieces with the help of jaw crusher [Fig. 3.3].

These pieces are then reduced to fine powder with the help of ball mill or stamp mill.

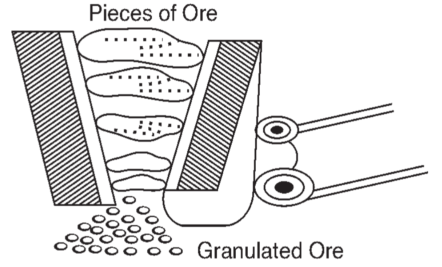


Fig. 3.3 Crushing & Grinding of Ore

(B) Concentration of the Ore

The process of removal of unwanted impurities (or gangue) from the ore is called ore concentration. The methods used for removing gangue from ore depend on differences in the some of the physical properties or chemical properties of the ore and gangue. After removing gangue, we get a concentrated ore containing much higher percentage of the metal. Concentration of Ores is carried out by physical concentration and Chemical Concentration method Physical Concentration methods are a) Gravity Separation b) Magnetic Separation c) Froth flotation. Chemical Concentration methods are a) Calcination b) Roasting

Following are some common methods of concentration of ores.

(i) Gravity Separation or Hydraulic Washing

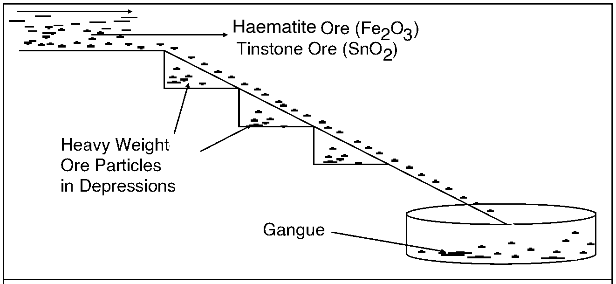


Fig 3.4 Gravity Separation

This method is based on difference in the densities of the ore particles and the impurities (gangue). The crushed ore is washed with a running stream of water or agitated with water. The heavy ore particles settle down rapidly and lighter gangue particles are washed away. Haematite (Fe_2O_3) and tinstone (SnO_2) ores are concentrated with this method. [Fig 3.4]

(ii) Froth Flotation Process

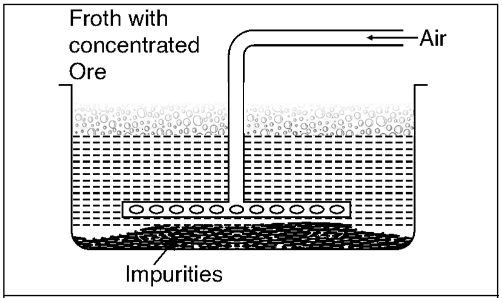


Fig. 3.5 Froth Flotation Process

This method is based on the principle of difference in the wetting properties of the ore and gangue particles with oil and water respectively. This method is used for concentration of sulphide ores. Crushed ore is taken in big iron tank containing water. Some pine oil is also added in the tank. The ore particles acquire an oily layer on their surface while the gangue particles get wetted with water and settle down under gravity.

Now a current of air is bubbled into the tank.

The oily ore particles come on the surface with the froth and the gangue particles settle down in the tank. The froth is removed from time to time and purified ore is obtained [Fig. 3.5]. Ores like zinc blende (ZnS), galena (PbS), cinnabar (HgS), nickel sulphide(NiS), copper pyrite ($CuFeS_2$) can be concentrated with this method.

(iii) Magnetic Separation

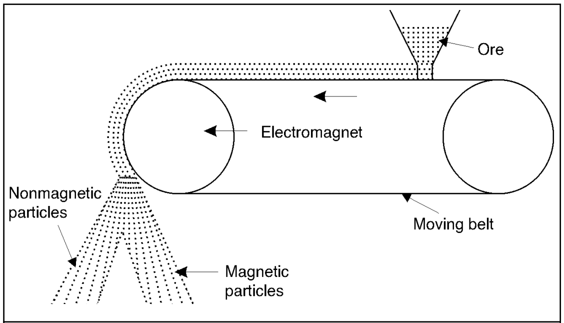


Fig. 3.6 Magnetic Separation Method

This method depends upon the difference in the magnetic properties of the ores and gangue. The crushed ore is spread over a moving belt in a strong magnetic field. When the ore falls down, the magnetic substances are attracted by the magnet and collected on one side. The nonmagnetic substances collect on the other side. This method is used for the concentration of haematite, an ore of the iron [Fig. 3.6]. Non magnetic ore like tinstone (SnO_2) can be concentrated from magnetic impurities like tungstates of iron and manganese.

Flux

The metal ores sometimes contains non-fusible impurities. They are fused easily with suitable substances called flux. The impurities react with flux forming a fusible product called slag which can be removed. Thus flux is a substance that chemically combines with gangue (earthy impurities), which may still be present in the roasted or calcined ore to form an easily fusible material called slag.

Flux + Gangue = Slag
(Earthy impurities)

The flux are of two types-

(a) Acidic Flux

If non-fusible impurities are basic, then the acidic flux is used.

Example

In the extraction of Copper, iron impurities are removed by SiO_2.

$$\underset{\text{Acidic flux}}{SiO_2} + \underset{\text{Basic impurity}}{FeO} \longrightarrow \underset{\text{Fusible slag}}{FeSiO_3}$$

(b) Basic Flux

CaO, MgO, FeO are the basic fluxes which are used when the non-fusible impurities are acidic.

$$\underset{\text{Basic flux}}{MgCO_3} + \underset{\text{Acidic impurities}}{SiO_2} \longrightarrow MgSiO_3 + CO_2\uparrow$$

$$\underset{\text{Basic flux}}{CaO} + \underset{\text{Acidic impurity}}{SiO_2} \longrightarrow \underset{\text{Fusible slag}}{CaSiO_3}$$

The slag is mostly silicate. It melts below the melting point of the metal and being lighter, floats on the metal surface in the furnace. It can be easily removed from the furnace.

SAQ 1	For purification of sulphide ores, one of the following method is used-			
	1. Gravity separation	2. Froth flotation	3. Magnetic separation	4. Calcination

Key: 2

(C) Extraction of Metal from the Concentrated Ore

Metal is extracted from the concentrated ore by the following steps

(i) Conversion of the Concentrated Ore into its Metal Oxide

The production of metal from the concentrated ore mainly involves reduction process. This can be usually done by two processes known as calcination and roasting depending upon the nature of the ore.

(a) Calcination

It is the process of heating the concentrated ore in the absence of air. It is used for hydrated and carbonate ores.

The calcinations process is carried out to

- convert carbonate ores into metal oxide.
- remove water from the hydrated ores.
- remove volatile impurities from the ore.

For example

$$\underset{\text{Calamine}}{ZnCO_3(s)} \xrightarrow{\text{Calcination}} \underset{\text{Zinc oxide}}{ZnO(s)} + \underset{\text{Carbon dioxide}}{CO_2(g)}$$

$$\underset{\text{Siderite}}{FeCO_3(s)} \xrightarrow{\text{Calcination}} \underset{\text{Iron(II) oxide}}{FeO(s)} + \underset{\text{Carbon dioxide}}{CO_2(g)}$$

$$\underset{\text{Haematite}}{Fe_2O_3.3H_2O} \xrightarrow{-H_2O} Fe_2O_3 + \underset{\text{Moisture}}{3H_2O}$$

$$\underset{\substack{\text{Malachite}\\\text{(Hydroxide)}}}{CuCO_3.Cu(OH)_2} \longrightarrow \underset{\text{(Oxide)}}{2CuO} + CO_2 + H_2O$$

(b) Roasting

It is the process of heating the concentrated ore strongly in the presence of excess air, below melting point of ore. This method is used for extraction of sulphide ores. This process is used for converting sulphide ores to metal oxide. In this process, the following changes takes place:

- the sulphide ores undergo oxidation to their oxides.
- the sulphide ores undergo oxidation to their sulphate.
- moisture is removed.
- volatile impurities are removed.

For example

$$\underset{\substack{\text{Zinc sulphide}\\\text{(Zinc blende)}}}{2ZnS(s)} + \underset{\text{Oxygen}}{3O_2(g)} \xrightarrow[\text{(from air)}]{\text{Roasting}} \underset{\text{Zinc oxide}}{2ZnO(s)} + \underset{\text{Sulphur dioxide}}{2SO_2(g)}$$

$$\underset{\text{Zinc sulphide}}{ZnS} + 2O_2 \longrightarrow \underset{\text{Zinc sulphate}}{ZnSO_4}$$

$$\underset{\text{Iron pyrites}}{4FeS_2(s)} + \underset{\text{Oxygen}}{11O_2(g)} \xrightarrow{\text{Roasting}} \underset{\text{Ferric oxide}}{2Fe_2O_3(s)} + \underset{\text{Sulphur dioxide}}{8SO_2(g)}$$

SAQ-2	**Write true or false**
1.	Calcination is the process of heating the concentrated ore in the absence of air.
2.	Roasting is the process of heating the concentrated ore in the presence of excess air.

Key : (1) True Key: (2) True

(ii) Conversion of Metal Oxide into Metal

The metal oxide formed after calcination or roasting is converted into metal by reduction. The method used for reduction of metal oxide depends upon the nature and chemical reactivity of metal. The metals can be grouped into the following three categories on the basis of their reactivity:

- Metals of low reactivity.
- Metals of medium reactivity.
- Metals of high reactivity.

These different categories of metals are extracted by different techniques. The different steps involved in separation are as follows

(a) Reduction by Heating

Metals placed low in the reactivity series are very less reactive. They can be obtained from their oxides by simply heating in air.

$$\underset{\text{Mercuric sulphide}}{2HgS(s)} + \underset{\text{Oxygen}}{3O_2(g)} \xrightarrow{\text{Roasting}} \underset{\text{Mercuric oxide}}{2HgO(s)} + \underset{\text{Sulphur dioxide}}{2SO_2(g)}$$

$$\underset{\text{Mercuric oxide}}{2HgO(s)} \xrightarrow{\text{Heat}} \underset{\text{Mercury metal}}{2Hg(l)} + \underset{\text{Oxygen}}{O_2(g)}$$

(b) Chemical Reduction

The metals in the middle of the reactivity series, such as iron, zinc, lead, copper etc. are moderately reactive. These are usually present as sulphides or carbonates. Therefore, before reduction, the metal sulphides and carbonates must be converted to oxides. This is done by roasting and calcinations. The oxides of these metals cannot be reduced by heating alone. Therefore, these metal oxides are reduced to the free metal by using reducing agents like carbon, aluminium, sodium or calcium.

Reduction with Carbon

The oxides of moderately reactive metals (occurring in the middle of reactivity series) like zinc, copper, nickel, tin, lead etc. can be reduced by using carbon as reducing agent. Coke is very commonly used as a reducing agent because it is cheap.

$$\underset{\substack{\text{Zinc oxide} \\ \text{(Reducing agent)}}}{ZnO(s)} + \underset{\substack{\text{Carbon} \\ \text{metal}}}{C(s)} \xrightarrow{\text{Heat}} \underset{\text{Zinc}}{Zn(s)} + \underset{\text{Carbon monoxide}}{CO(g)}$$

$$\underset{\text{Ferric oxide}}{Fe_2O_3(s)} + \underset{\text{Carbon}}{3C(s)} \longrightarrow \underset{\text{Iron metal}}{2Fe(s)} + 3CO(g)$$

$$\underset{\text{Lead oxide}}{PbO(s)} + \underset{\text{Carbon}}{C(s)} \longrightarrow \underset{\text{Lead metal}}{Pb(s)} + CO(g)$$

Disadvantage of using carbon as reducing agent is that small traces of carbon are added to metal as impurity, which contaminates the metals.

Reduction with Carbon Monoxide

Metals can be obtained from oxides by reduction with carbon monoxide in the furnace.

$$\underset{\text{Ferric oxide}}{Fe_2O_3(s)} + \underset{\text{Carbon monoxide}}{3CO(g)} \xrightarrow{\text{Heat}} \underset{\text{Iron}}{2Fe(s)} + \underset{\text{Carbon dioxide}}{3CO_2(g)}$$

Reduction with Aluminium

Alumino-Thermic Process

This method is used to reduce such metallic oxides (eg. Cr_2O_3, MnO_2) which cannot be reduced by carbon. Here metal oxide is mixed with aluminium powder and the mixture is taken in a crucible. This mixture is ignited by means of magnesium ribbon, inserted into aluminium and

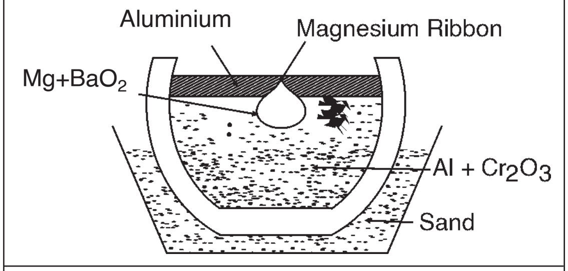


Fig. 3.7 Alumino Thermic Process

barium peroxide mixture inside the crucible. The reaction is exothermic and produce a very high temperature of about 3000^{0}C. The oxide is reduced into metal and Al_2O_3 is formed. [Fig.3.7]

$$Cr_2O_3 + 2Al \xrightarrow{\quad} Al_2O_3 + 2Cr + Heat$$

$$3MnO_2 + 4Al \xrightarrow{\quad} 2Al_2O_3 + 3Mn + Heat$$

The impurities are removed as slag by heating the metal with suitable flux.

(c) Reduction by Electrolysis or Electrolytic Reduction

The oxides of active metals (which are high up in the activity series) are very stable and cannot be reduced by carbon or aluminium. These metals are commonly extracted by the electrolysis of their fused salts using suitable electrodes. This is also called electrolytic reduction i.e. reduction by electrolysis. The process of extraction of metals by electrolysis process is called electrometallurgy.

Example

Aluminium oxide is very stable and aluminium cannot be prepared by reduction with carbon. It is prepared by the electrolysis of molten alumina (Al_2O_3).

$$\underset{\text{(From molten alumina)}}{\underset{\text{Aluminium ion}}{Al^{3+}}} + \underset{\text{(From cathode)}}{\underset{\text{Electrons}}{3e^-}} \xrightarrow{\text{Heat}} \underset{\text{(At cathode)}}{\underset{\text{Aluminium}}{Al}}$$

During electrolytic reduction of molten salts, the metals are always obtained at the cathode (negative electrode).

(D) Purification of Metals

The metals obtained by any of the above methods are usually impure and is known as crude metal. The process of purifying the crude metal is called refining.

(i) Liquation

This is based on the principle that the metal to be refined is easily fusible but the impurities do not fuse easily. The impure metal is placed on the sloping hearth of a furnace and gently heated. The metal melts and flows down leaving behind the impurities on the hearth. This method is used for refining the metals having low melting points, such as tin, lead, bismuth etc.

(ii) Distillation

This method is used for the purification of volatile metals. Impure metal is heated and its vapours are separately condensed in a receiver. The non-volatile impurities are left behind. This is used for mercury, cadmium and zinc.

(iii) Electrolytic Refining

This is most widely used method for the refining of impure metals. In this method impure metal is made anode while pure

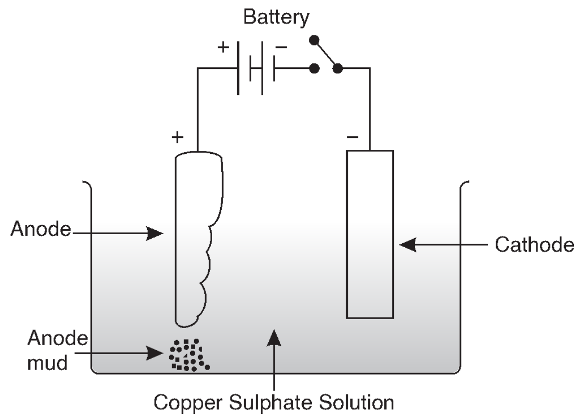


Fig. 3.8 Electrolytic Refining of Copper

metal is made cathode. Many metals such as copper, zinc, tin, nickel, silver, gold etc. are refined electrolytically. It is based upon the phenomenon of electrolysis. In this method, the crude metal is casted into thick rods and is made as anode. An aqueous solution of salt of the same metal is used as an electrolyte [Fig.3.8].On passing current through the electrolyte, the pure metal from the anode dissolves into the electrolyte. An equivalent amount of pure metal from the electrolyte is deposited on the cathode. The soluble impurities go into the solution whereas the insoluble impurities settle down at the bottom of the anode and are known as anode mud. In this way, the pure metal from anode goes into electrolyte and from electrolyte it goes to the cathode.

$$\text{At anode:} \quad \underset{\substack{\text{Copper} \\ \text{(from impure anode)}}}{Cu} \xrightarrow{\text{Oxidation}} \underset{\text{Cupric ion}}{Cu^{2+}} + 2e^-$$

$$\text{At cathode:} \quad \underset{\text{Cupric ion}}{Cu^{2+}} + 2e^- \xrightarrow{\text{Reduction}} \underset{\text{(deposited at cathode)}}{Cu}$$

3.1.3 Extraction of Iron from Haematite

Iron is extracted in three forms; Cast Iron, Wrought Iron and Steel.

Iron is usually extracted from the oxide ore, i.e. haematite. It involves the following steps:

(A) Concentration

The ore is crushed in jaw crushers and the crushed ore is concentrated by gravity separation process in which the crushed ore is washed in a stream of water when lighter sand and clay particles are washed away while the heavier ore particles settle down. In case of sulphide ore i.e. iron pyrites concentration is carried out by froth floatation process.

(B) Calcination

The concentrated ore is then calcined i.e., heated strongly in the presence of a limited supply of air in a reverberatory furnace [Fig. 3.9]. During calcination, the following changes occur.

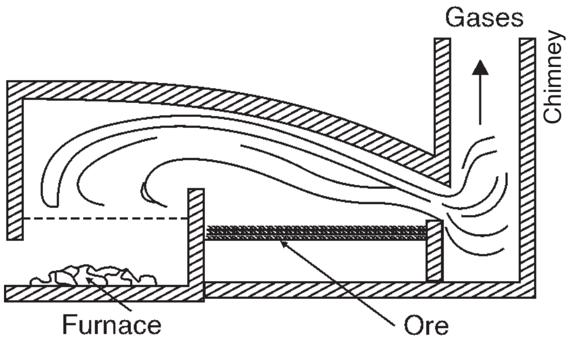


Fig. 3.9 Reverberatory Furnace

(i) Moisture is removed.

(ii) Impurities of sulphur, phosphorus & arsenic escape as their volatile oxides.

$$S_8 + 8\,O_2 \longrightarrow 8\,SO_2$$

$$P_4 + 5\,O_2 \longrightarrow P_4O_{10}$$

$$4As + 5\,O_2 \longrightarrow 2As_2O_5$$

(iii) Ferrous oxide is oxidised to ferric oxide thereby preventing the loss of iron as slag during smelting

$$4\,FeO + O_2 \longrightarrow 2Fe_2O_3$$

(iv) The ore becomes porous and hence is more suitable for reduction to the metallic state.

In case of carbonate ore i.e. siderite, during calcination, it is converted into ferric oxide.

$$FeCO_3 \longrightarrow FeO + CO_2 \quad , \quad 4FeO + O_2 \longrightarrow 2Fe_2O_3$$

However, in case of sulphide ore i.e. iron pyrites, conversion to oxide is carried out by roasting.

$$4FeS_2 + 11\,O_2 \xrightarrow{\hspace{2cm}} 2Fe_2O_3 + 8\,SO_2$$

(C) Smelting

The calcined ore is reduced with carbon, i.e., smelted in a blast furnace [Fig. 3.10]. It is a tall cylindrical furnace made of steel and lined inside with refractory material. It is slightly narrow at the top and again at the bottom. This facilitates the proper flow of materials. The furnace is provided with a double cup and cone arrangement which helps to feed the charge from the top without letting any gases from inside to escape. Near the top, furnace is also provided with an outlet for waste gases. At the base, the furnace is provided with-

(i) small pipes called tuyeres through which a blast of hot air is flown inside.
(ii) a tapping hole for with drawing molten iron.
(iii) a slag hole for withdrawing slag.

The charge consisting of calcined ore (8 parts), coke (4 parts) and limestone (1 part) is introduced into the furnace from the top through cup and cone arrangement. At the same time, a blast of hot air pre-heated to about 1000 K is blown into the furnace through tuyeres. The added coke serves both as a fuel as well as a reducing agent while added limestone acts as the basic flux.

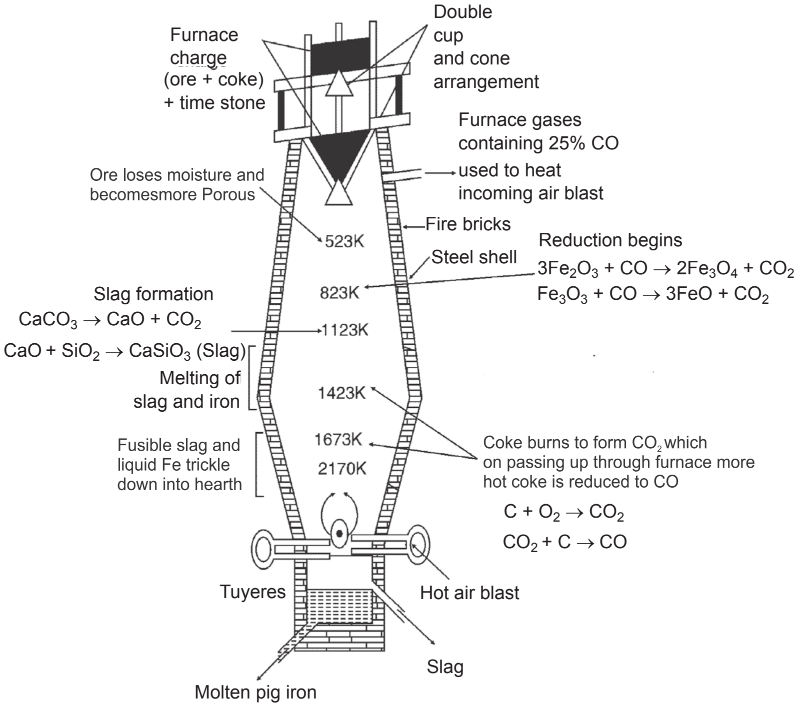


Fig. 3.10 Blast Furnace

(D) Reduction of Iron oxide in the Blast Furnace

In the blast furnace, reduction of iron oxides takes place in different temperature ranges as summarised below

At 500-800 K (lower temperature range in the blast furnace)

$3\ Fe_2O_3 + CO \longrightarrow 2Fe_3O_4 + CO_2$

$Fe_3O_4 + 4CO \longrightarrow 3Fe + 4CO_2$

$Fe_2O_3 + CO \longrightarrow 2FeO + CO_2$

At 900-1500 K (higher temperature range in the blast furnace)

$C + CO_2 \longrightarrow 2CO$

$FeO + CO \longrightarrow Fe + CO_2$

(E) Reactions in the Blast Furnace

The following reactions occur in the blast furnace.

(i) Zone of Combustion

Near the tuyeres, coke burns to form carbon dioxide.

$C + O_2 \longrightarrow CO_2 ; \triangle H = -393.3\ kJ$

Since the reaction is exothermic, lot of heat is produced and the temperature here is around 2170 K.

(ii) Zone of Heat Absorption

This is lower part of the furnace and the temperature here is between 1423-1673 K. As CO_2 formed near tuyeres moves up, it meets the descending charge. The coke present in the charge reduces CO_2 to CO.

$CO_2 + C \longrightarrow 2\ CO ; \triangle H = +\ 163.2\ kJ$

Since this reaction is endothermic, the temperature gradually falls to 1423 K.

(iii) Zone of Slag Formation

It is the middle part of the furnace. The temperature here is around 1123 K. In this region, limestone decomposes to form CaO and CO_2. The CaO thus formed acts as a flux and combines with silica (present as an impurity) to form fusible calcium silicate slag

$CaCO_3\ (s) \longrightarrow CaO\ (s) + CO_2\ (g)$

$CaO + SiO_2 \longrightarrow \underset{\text{Calcium silicate (slag)}}{CaSiO_3}$

(iv) Zone of Reduction

This is the upper part of the furnace. The temperature here is around 823 K. Here, the ores are reduced to FeO by CO.

$Fe_2O_3 + CO \xrightarrow{823\ K} 2\ FeO + CO_2$

$Fe_3O_4 + CO \xrightarrow{823\ K} 3\ FeO + CO_2$

Further reduction of FeO to Fe by CO occurs around 1123 K

$$FeO + CO \xrightarrow{1123\ K} Fe + CO_2$$

Direct reduction of iron ore occurs above 1123K

$$Fe_2O_3 + 3C \xrightarrow{>1123\ K} 2\ Fe + 3\ CO$$

(v) Zone of fusion

This is the lower part of the furnace. Temperature here is in between 1423-1673 K. In this region, spongy iron melts and dissolves some C, S, P, Si, Mn, etc. $CaSiO_3$ slag also melts in this region. Both the molten slag and the molten iron trickle down into hearth where they form two separate layers. The molten $CaSiO_3$ slag being lighter, forms the upper layer while molten iron being heavier forms the lower layer. The two liquids are periodically tapped off. The iron thus obtained from the furnace contains about 4% carbon and many impurities in smaller amount (e.g., S, P, Si, Mn). This is called pig iron and is cast into variety of shapes. Cast iron is different from pig iron and is made by melting pig iron with scrap iron and coke using hot air blast. It has slightly lower carbon content (about 3%) and is extremely hard and brittle.

Preparation of Wrought Iron

Wrought iron is the purest form of commercial iron. It contains about 0.2-0.5% carbon, besides traces of P and Si in the form of slag. Carbon in wrought iron is present partly as graphite and partly as cementite, Fe_3C. Wrought iron is ductile, soft and malleable. The presence of slag in it makes it tough and resistant towards rusting and corrosion. It is, therefore, used to make chains, anchors, bolts, nails and railway carriage couplings. It can be easily magnetised and hence it is used to make magnets in electric cranes and dynamos.

Wrought iron is prepared from cast iron by decreasing the carbon content and oxidising the impurities (S, P, Si, Mn, etc.) in a reverberatory furnace lined with haematite. The haematite oxidises C to CO, S to SO_2, Si to SiO_2, P to P_4O_{10} and Mn to MnO.

$$Fe_2O_3 + 3\ C \longrightarrow 2\ Fe + 3\ CO$$

$$2Fe_2O_3 + 3\ S \longrightarrow 4\ Fe + 3\ SO_2$$

CO and SO_2 thus formed escape whereas manganous oxide (MnO) and silica (SiO_2) combine to form slag.

$$MnO + SiO_2 \longrightarrow \underset{\text{Manganous silicate (slag)}}{MnSiO_3}$$

Similarly, phosphorus pentoxide combines with haematite to form ferric phosphate slag.

$$2Fe_2O_3 + P_4O_{10} \longrightarrow \underset{\text{Ferric phosphate (slag)}}{4FePO_4}$$

In this way, all the impurities are removed, the iron thus obtained is transformed into small balls. Slag is removed by hammering the balls. The iron thus obtained is called wrought iron. It is extremely tough and tenacious metal with a high melting point. It is used in making iron sheets, wire, chains, rails, rods etc.

After the reduction, the metal is removed from the furnace and is freed from the slag by passing through rollers.

Steel

Steel is iron containing 0.2 to 2% carbon which is intermediate between cast iron and wrought iron. It is prepared from both the type of iron, cast iron and wrought iron.

SAQ3	One of the following is the purest form of iron		
	1. Cast Iron	2. Wrought Iron	3. Steel

Key : 2

3.1.4 Extraction of Aluminium from Bauxite

(A) Introduction

Bauxite is the main ore of aluminium from which the metal is extracted. Extraction of aluminium is done by the reduction of bauxite ore. Electrode Potential of aluminium is high and hence aluminium oxide can not be reduced by chemical reducing agents. The extraction of metal is done by electrolytic reduction method. The process is carried out in three steps.

- Purification of Bauxite.
- Electrolysis of Bauxite.
- Purification of Aluminium.

(B) Purification of Bauxite

The ore contains about 55% Al_2O_3 along with impurities of Fe_2O_3, SiO_2, TiO_2 etc. If the metal is extracted from crude alumina, it is contaminated with these impurities which make it brittle. Hence it is necessary to purify the ore. It is done by the following methods.

(i) Hall's process

In this process bauxite ore is powdered and fused with sodium carbonate. Alumina reacts with Na_2CO_3 producing sodium aluminate while Fe_2O_3 and SiO_2 are not affected. This mixture is agitated with water to dissolve the aluminate. The insoluble impurities are removed by filtration.

$$Al_2O_32H_2O + Na_2CO_3 \longrightarrow 2NaAlO_2 + CO_2 + 2H_2O$$

The solution thus obtained is heated to 50-60°C and carbon dioxide is passed.

The aluminate is hydrolysed to aluminium hydroxide which is precipitated.

$$2NaAlO_2 + CO_2 + 3H_2O \longrightarrow 2Al(OH)_3\downarrow + Na_2CO_3$$

This precipitate is filtered and heated to 1500°C to get pure Alumina.

$$2Al(OH)_3 \longrightarrow Al_2O_3 + 3H_2O$$

(ii) Bayer's process

When the bauxite ore contains high percentage of Fe_2O_3 impurity, Bayer's process is employed. The crushed ore is roasted to convert FeO, if present, into Fe_2O_3. The roasted ore is treated with a strong solution of caustic soda at 15°C and 80 atmospheric pressure for several hours in an autoclave. Aluminium oxide reacts with alkali forming soluble sodium aluminate complex salt. The impurities remain in the form of precipitate which is filtered.

$$Al_2O_3 + 2NaOH \longrightarrow 2NaAlO_2 + H_2O$$

Seeding

In the solution of sodium aluminate, a small quantity of freshly precipitated aluminium hydroxide is added and the mixture is agitated for several hours. Sodium aluminate gets hydrolysed into aluminium hydroxide. The ppt of $Al(OH)_3$ is filtered and dried. It is then heated to 750^0C to get pure Al_2O_3.

$$NaAlO_2 + 2H_2O \longrightarrow NaOH + Al(OH)_3$$

$$2Al(OH)_3 \longrightarrow Al_2O_3 + 3H_2O$$

(iii) Serpek's process

This process is used to purify bauxite having much silica (SiO_2) as impurity. The ore is first powdered. It is then mixed with carbon and the mixture is heated to 1800^0C in a current of nitrogen. Aluminium is converted into aluminium nitride. The Silica of bauxite is reduced to silicon which, being volatile, escapes as vapour.The product obtained is allowed to react with hot water when it forms a precipitate of aluminium hydroxide. The precipitate is filtered, dried and heated to 1500^0C to get pure Al_2O_3.

$$Al_2O_3 + 3C + N_2 \xrightarrow{1800^0C} \underset{\text{Aluminium nitride}}{2AlN} + 3CO$$

$$AlN + 3H_2O \longrightarrow Al(OH)_3 + NH_3$$

$$SiO_2 + 2C \longrightarrow 2CO + Si$$

$$2Al(OH)_3 \xrightarrow{1500^0C} Al_2O_3 + 3H_2O$$

SAQ 4	During purification of bauxite by Bayer's process, ---------- is added to sodium aluminate for seeding purpose.	
	1. Sodium Hydroxide	2. Magnesium Hydroxide
	3. Aluminium hydroxide	4. Aluminium Chloride

Key:3

(C) Electrolysis of Bauxite

The purified bauxite is mixed with fused mixture of cryolite and fluorspar and is taken in an iron tank. The purpose of taking cryolite is to reduce the melting point of alumina from 2050^0C to only 900^0C. Moreover, cryolite is used as an electrolyte also. The iron tank has a thick inner lining of carbon which serves as cathode [Fig.3.11]. The anode is made of graphite rods which are suspended in the fused mixture. An electric bulb is connected in parallel with the electrolytic cell. Some powdered charcoal is spread over the surface to check the glow produced by the vigorous action of oxygen at the anodes. A current of 6-7 volts and 100 amperes is passed through the cell. The high current brings about the following changes and also it maintains a temperature of about

900°C which keeps the mass in molten form. Cryolite is a mixed fluoride of Sodium and aluminium which decomposes into sodium fluoride.

$$Na_3AlF_6 \longrightarrow 4NaF + AlF_3$$

AlF_3 undergoes electrolysis as follows :

$$AlF_3 \longrightarrow Al^{3+} + 3F^-$$

$$Al^{3+} + 3e^- \longrightarrow Al \quad \text{at cathode.}$$

$$3F^- \longrightarrow 3F + 3e^- \quad \text{at anode.}$$

Aluminium is deposited at cathode and is collected from the bottom of the tank. Fluorine is liberated at anode which reacts with alumina producing aluminium fluoride & oxygen.

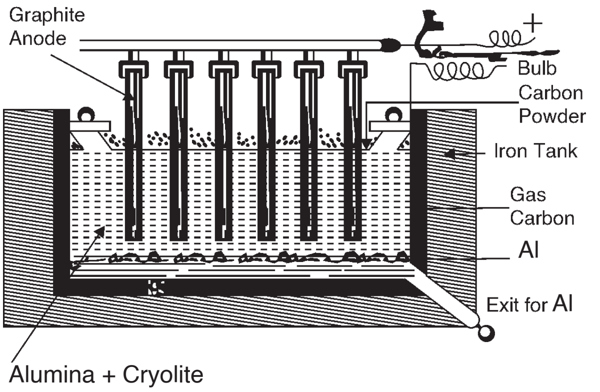


Fig.3.11 Electrolysis of Bauxite

$$2Al_2O_3 + 12F \longrightarrow 4AlF_3 + 3O_2$$

In this way alumina is decomposed and Al metal is obtained. The oxygen liberated at anode reacts with the carbon of anode forming CO and CO_2. Thus the anode gets smaller and smaller. This is checked by the charcoal powder spread over the surface. As more and more Al_2O_3 is decomposed, the resistance of the cell increases. It is indicated by the glowing of electric bulb connected with the cell. More alumina is added to continue the process. Aluminium obtained by this process is about 99%.

(D) Purification of Aluminium

The metal obtained from the above process contained the impurities of iron and silicon. The method is called Hoope's method.Purification is done in an iron tank having a lining of carbon at its bottom which acts as anode. The electrolytic cell contains three liquids layers of different densities. The lowermost layer is of molten impure aluminium which is in contact with carbon anode. The middle layer is a fused mixture of sodium, aluminium and barium fluorides and the top layer is of molten pure aluminium in which carbon rods are dipped which act as cathode [Fig.3.12]

When current is passed, Al^{3+} ions come in the middle layer migrate towards the top layer of pure aluminium cathode and are discharged. More Al^{3+} ions come in the middle layer from the impure aluminium anode. In this way pure aluminium collects at the top and is removed from time to time. The metal thus obtained is 99.94% pure.

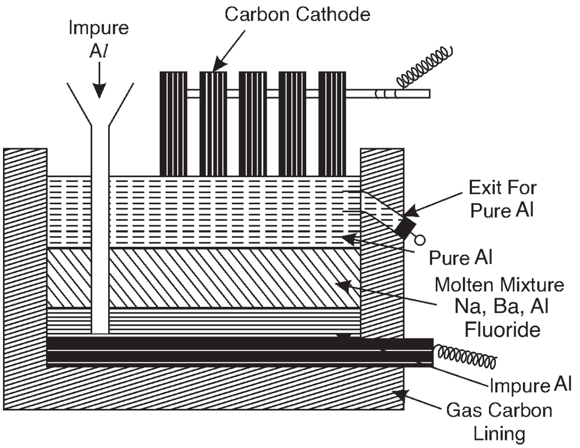


Fig. 3.12 Purification of Aluminium

3.1.5 Alloys

An **alloy** is a homogenous mixture of two or more metals or a metal and a non-metal.

For example, iron is the most widely used metal. But it is never used in the pure form. This is because iron is very soft and stretches easily when hot. But when it is mixed with a small amount of carbon (about 0.5 to 1.5%), it becomes hard and strong. The other form of iron is called steel.

(i) Objectives of Alloy Making

Alloys are generally prepared to have certain specific properties which are not possessed by the constituent metals.

The main purposes of alloy-making are to-

- **increase resistance to corrosion** – Pure metals are more reactive and easily corroded by surrounding atmosphere hence their life is reduced. But if a metal is alloyed, it is resistant to corrosion. Alloys are more resistant to corrosion than pure metals. Stainless steel is prepared by alloying which has more resistance to corrosion than iron.
- **modify chemical reactivity** – Chemical reactivity can be altered by alloying with other metal. The chemical reactivity of sodium is decreased by making an alloy with mercury which is known as sodium amalgam. Similarly, the reactivity of aluminium is increased by making alloy with mercury which is known as aluminium amalgam
- **increase the hardness** – Pure metals are soft, but when metal is alloyed with another element, its hardness is increased. Steel, an alloy of iron and carbon is harder than iron.
- **increase tensile strength** – Tensile strength gives information about the ability of the metal to carry the load without breaking. Magnalium is an alloy of magnesium and aluminium. It has greater tensile strength as compared to magnesium and aluminium. By adding 1% C in iron, tensile strength of iron increases ten times. While the addition of 5% silicon, tensile strength of Cu is doubled
- **produce good casting** – To get good casting from metal or alloy, the metal must expand on solidification. It should be fusible so that a sharp impression can be taken easily. Generally, pure molten metals contract on solidification. Hence to get good casting, metals have to be alloyed because alloys expand on solidification. Type metal is an alloy of lead, tin and antimony.
- **lower the melting point** – When an alloying element is added to base metal (metal in higher %), it acts as an impurity in base metal, and the melting point of base metal is lowered. The melting point of an alloy is lower than those of a constituent element. Solder is an alloy of lead and tin (50% Pb and 50% Sn). It has a low melting point and is used for welding electrical wires together.

Classification of Alloys

Alloys are classified as follows

- **Ferrous Alloy :** Alloys which contain iron as one of the main component known as ferrous alloys. e.g. In stainless steel alloy, Fe is present as one of the main component with Cr and Ni.
- **Non-ferrous Alloys :** Alloys which do not contain iron as one of the main component known as non-ferrous alloys. e.g. Brass consist of Cu and Zn, it does not contains iron hence it is non-ferrous alloy.

The composition, properties and uses of some alloys of Copper (table 3.3), Iron (table 3.4) and Aluminium (table 3.5) are given below.

Table 3.3 Composition, Properties and Uses of Some Alloys of Copper

Sl. No.	Alloys	Composition	Properties and Uses
1.	Brass	Cu (60-80%) Zn (20-40%)	Brass is used for decoration purposes, for making many scientific instruments, telescopes, microscopes, barometers etc.
2.	Bronze	Cu (75-90%) Sn (10-25%)	It is used for making statues, cooking utensils and coins.
3.	German Silver	Cu (30-60%) Zn (25-35%) Ni(15-35%)	It is silvery white. Malleable and ductile. It is used as imitation silver, in making ornaments and utensils and also for decoration.
4.	Gun metal	Cu (88%) Sn (10%) Zn (2%)	It is used for making gears, bearing and gun barrels.
5.	Bell metal	Cu (80%) Sn (20%)	It is used for casting bells.
6.	Aluminium Bronze	Cu 90% Al 10%	Golden yellow, used for cheap jewellery, coins, paints etc.
7.	Monel metal	Cu 30% Ni 67% Fe+Mn 3%	Pumps and containers for acids, caustic alkali industry
8.	Manganin	Cu 82% Ni 3% Mn 1%	Electrical apparatus
9.	Muntzmetal	Cu 60% Zn 40%	Covering of wooden ships

Table 3.4 Composition, Properties and Uses of Some Alloys of Iron

Sl. No.	Alloys	Composition	Properties and Uses
1.	Stainless steel	Fe (74%) Cr (18%) Ni (8%)	Stainless steel is hard, tenacious and corrosion resistant. It is used for making cutlery, utensils, ornamental pieces, Instrument, apparatus, cycle and automobile parts
2.	Nickel steel	Fe (96-98%) Ni (2-4%)	Nickel steel is hard, elastic and corrosion resistant. Used for making electric wire cables, automobile and aeroplane parts, watches, armour plates, propeller shafts, etc.
3.	Alnico	Fe (60%) Al (12%) Ni (20-%) Co (8%)	It is highly magnetic. Used for making permanent magnets

Sl. No.	Alloys	Composition	Properties and Uses
4.	Chrome Vanadium Steel	Fe (98.75%) Cr (1%) V (0.15%)	In manufacturing springs, axles, shafts and motor car frames.
5.	Manganese steel	Fe (63-75) Mn (12-15%) C (0.8-1.2%)	Used for making rock cutting machine, burglar proof safes, rail road tracks etc.
6.	Tungsten steel	Fe (83-78%) W (14%) Cr (3-8%)	For high speed tools.

Table 3.5 Composition, Properties and Uses of Some Alloys of Aluminium

Sl. No.	Alloys	Composition	Properties and Uses
1.	Duralium or Duralumin	Al (95%) Cu (4%) Mg (0.5%) Mn (0.5%)	Its strength is comparable to steel but it is very light. It is hard, corrosion-resistant and highly ductile. Used for making aeroplane, spacecrafts, ships and pressure cookers.
2.	Magnalium	Al (90-95%) Mg (5-10%)	Used for making light instruments, balance beams and parts of machine.
3.	Aluminium Bronze	Cu (88-90%) Al (10-12%)	Used for making cooking utensils, photo frames, coins.
4.	Y-alloy	Al (92.5%) Cu (4%) Mg (1.5%) Ni (2%)	Used for casting and forging.
5.	Nickeloy	Al (95%) Ni (2%) Cu (4%)	Used for making airships
6.	Alnico	Fe (50%) Al (20%) Ni (20%) Co (10%)	Used for making permanent magnet

3.2 GENERAL CHEMICAL COMPOSITION, COMPOSITION BASED APPLICATIONS OF ENGINEERING MATERIALS

Interesting Fact: The process of wetting quicklime with water is called slaking of lime i.e. Calcium hydroxide $Ca(OH)_2$. A clear solution of $Ca(OH)_2$ in water is called lime water.

Materials used in manufacturing and construction of buildings, where particular requirements are needed, are called engineering materials. These include cement, glasses, refractories, and composite materials.

Cement

Cement may be broadly described as a finely ground mixture of various metals and non-metal oxides of different compositions with adhesive and cohesive properties. It helps in bonding of materials like stones, bricks, and other building blocks. The cement has the peculiar property of setting and hardening in contact with water hence is called hydraulic cement.

Different types of cement are used for construction purposes. They differ in their composition and are manufactured for various uses. Some different types of cement are portland cement or ordinary portland cement (OPC), quick setting cement (QSC), low heat cement (LHC), sulphate-resisting cement (SRC), blast furnace slag cement (BFSC), white cement (WC), coloured cement (CC), pozzolanic cement (PzC), rapid hardening cement (RHC) ,air entraining cement (AEC), hydrophobic cement (HpC), expanding cement (EC), natural cement (NC), high alumina cement (HAC)

(A) Portland Cement

Portland cement is a mixture of metal and non-metal oxides along with gypsum. When cement is mixed with an adequate quantity of water, it forms a paste with the property of setting in a short time also becomes rigid and durable on standing.

> Cement manufactured from chalk and clay which hardens in contact with water and on hardening, resembles Portland stone in colour hence called Portland cement.

Analysis of portland cement gives information about silica, alumina, iron, magnesia, etc., in various proportions, as shown in table 3.6. Although the analysis of cement gives an idea about the constituent present, it does not indicate how these constituents are combined in it. During the manufacturing of cement, the ingredients of raw materials merged to form the compound. The main compounds present in the finished product are given in table 3.7. It is clear from the table that lime is the main ingredient forming about 2/3 rd of the cement.

Table 3.6 Composition of Portland Cement

Compounds	% Range	Purposes of addition
Lime (CaO)	60-67	Increases the setting time
Silica (Silicon Oxide - SiO_2)	17-25	Increases the setting time makes cement liable to expand and crack, strength by forming gel
Alumina (Aluminium Oxide - Al_2O_3)	3-8	Reduce the setting time but increases the strength
Iron oxide (Ferric Oxide - Fe_2O_3)	0.5-6	Strength,hardness and colour
Magnesia (Magnesium Oxide - MgO)	0.1-4	Helps for expansion, reduces tensile stresses in concrete
Sulphur trioxide (SO_3)	1-2	Increases expansion in lime and sulphate. Beyond 3% increases the drying shrinkage
Soda + Potash ($Na_2O + K_2O$)	0.5 -1.3	Increases early hardening

Table 3.7 Average Compound Composition of Portland Cement

Abbreviation	%	Setting Days	Properties and uses
C2S	25	28	Hydrates and hardens slowly. It is largely responsible for strength gain after one week.

Abbreviation	%	Setting Days	Properties and uses
C3S	45	7	Hydrates and hardens rapidly,responsible for initial set and early strength
C3A	10	1	Liberates a lot of heat during the early stages of hydration, but has little strength contribution, Cement low in C3A is sulphate resistant.
C4AF	10	1	Fluxing agent which reduces the melting temperature of the raw materials in the kiln (from 1430^{0}C to 1650^{0}C). It hydrates rapidly, but does not contribute much to strength of the cement paste.
$CaSO_4$ Gypsum	4	-	Slows down the hydration rate of C3A, to retard this initial set.
CaO	2	-	Increases the setting time
MgO	4	-	Helps for expansion, reduces tensile stresses in concrete

Legend: C - Calcium oxide(CaO), A- Aluminium oxide (Al_2O_3), F - Fe_2O_3, S - SiO_2., C2S - Dicalcium silicate, C3S - Tricalcium silicate, C3A - Tricalcium aluminium, C4AF - Tetracalcium alumino ferrite, $CaSO_4$ - Copper sulphate (Gypsum), MgO - Magnesium oxide.

(B) Hardening of Portland Cement

When cement is mixed with water, a plastic mass called cement paste becomes rigid when a short time is known as the initial set or flash state. The setting and hardening of cement are mainly due to hydration and hydrolysis reactions taking place. Hydration is not the absorption of water or surface condensation but is taking up the water elements into the compound's crystal structure. Anhydrous compounds react with water and undergo hydration resulting in the formation of insoluble gels and crystalline products. The process of setting and hardening of cement is believed to be partly chemical change and somewhat physical.

Hydrolysis and hydration and of cement are mentioned below.

Hydrolysis

(a) $C3S + (x+1)H_2O \longrightarrow C2S.xH_2O\text{ (gel) } + C.\ H_2O\text{ (Crystals)}$

(b) $C4AF + 7H_2O \longrightarrow C2A.6H_2O\text{(crystals)}+CF.H_2O\text{(gel)}$

Hydration

(c) $C3S\ +xH_2O \longrightarrow C2S.XH_2O\text{(gel) } +CaO\text{(lime)}$

The gel is a bonding material and gives strength to cement.

(d) $C3A + 6H_2O \longrightarrow C3A\ .6H_2O\text{(crystals)} + \text{heat}$

Hydration reaction is responsible for the initial set of cement.

The hydrated tricalcium aluminate (C3A) generally exist as Cubic - $C3A.6H_2O$, Hexagonal-$C3A.12H_2O$, Orthorhombic-$C3A.18H_2O$. The setting and hardening of cement are due to interlocking crystals reinforced by the rigid gels. Finally, they bind the inert particles of aggregates like sand and crushed stones into a compact rock-like material. This solid mass on setting and hardening has excellent mechanical strength and forms a valuable building material. The process of solidification comprises setting and hardening. The setting is defined as stiffening of the original plastic mass due to initial gel formation. Hardening is the development of strength due to crystallisation. After setting, hardening starts due to the gradual process of crystallisation into the interior of the mass. The strength developed by cement paste at any time depends upon the amount of gel formed and the extent of crystallisation.

(C) Applications of Portland Cement

Portland cement is used in wide variety of applications as follows-

- Production of concrete and mortar for masonry work.
- Laying floors, roofs, constructing lintels, beams, weather sheds, stairs, pillars, etc.
- Construction of essential engineering structures such as bridges, culverts, dams, tunnels, storage reservoirs, lighthouses, docks etc.
- Construction of water tanks, tennis courts, septic tanks, lamp posts, roads, telephone cabins, etc.
- Making of joints for drains, pipes etc.
- Manufacture of precast pipes, garden seats, artistically designed urns, flower pots, dust bins, fencing posts, etc.
- Preparation of foundations, watertight floors, footpaths, etc.
- Creating fire-proof structures in the form of concrete, making acid-resistance and waterproof structures.
- Structuring the tunnel or geological walls to strengthen the structure.
- Coloured cement can be used for decorating or colouring the structures.

SAQ 5	________ is not used to make portland cement.			
	1. Gypsum	2. Sand	3. Fe_2O_3	4. Al_2O_3

Key : 2

3.2.2 GLASS

Glass is an amorphous, hard, brittle transparent or translucent or super cooled liquid of infinite viscosity having no definite melting point. It is obtained by fusing a mixture of several metallic silicates or borates of sodium, potassium, calcium and lead.

(A) Composition of Glass

Glass is made from the materials shown in table 3.8

Properties of Glass

- **Hardness and Brittleness-** It is a hard material as it has great impact resistance against applied load. However, at the same time, it is a brittle material as its breaks immediately when subjected to load.
- **Weather Resistance-** It is weather resistant as it can withstand the backlash of rain, sun and wind. It can absorb, reflect and refract
- **Fire Resistant-** Glass protect heat from 200^0C to 800^0C.

Making of Glass

- **Insulation-** It is an excellent insulator against heat, electricity and electromagnetic radiation because of its good insulating response against visible light transmission.
- **Chemical Resistance-** It can withstand the effect of the chemical reaction under different environment conditions or acidic effects.
- **Colour and Shape Varieties-** It can be blown, drawn and pressed to any colour, shape, and variety and is available in the market depending upon their use, dimensional requirements, and safety requirement.
- **Transparency-** The transparency is one such property of glass which creates a visual connect with the outside world. With the advent of technology, clear glass can also be altered, making it opaque.
- **Property Modification-** It is also possible to modify some of its properties to suit different purposes.

Table 3.8 Composition of Glass

Sr. No.	Compound Used	Formula	% Proportion
1	Silica	SiO_2	71 to 78
2	Alumina	Al_2O_3	0.5 to 1.5
3	Iron Oxide	Fe_2O_3	0.05 to 0.15
4	Calcium Oxide	CaO	5 to 10
5	Magnesium Oxide	MgO	2 to 5
6	Sodium Oxide	Na_2O	13 to 16
7	Potassium Oxide	K_2O	0 to 1
8	Sulphur Trioxide	SO_3	0 to 0.5

(B) Applications of Different types of Glasses

Different types of glasses and their uses are mentioned in the table 3.9

Table 3.9 Types of Glasses and their Uses

Types of glass	Uses
Soda-lime glass or soft glass	Window glass, electric bulbs, plate glass, bottles, jars, test tubes, and reagent bottles
Potash lime glass	Chemical apparatus, combustion tubes, and glassware used for heating operations
Lead glass	High-quality tableware, optical lenses, neon sign tubings, cathode ray tubes, electrical insulation windows, and shields for protection against X-rays, gamma rays, medical and atomic energy fields
Borosilicate glass	Corrosive liquids, superior chemistry laboratory apparatus, kitchen wares, chemical plants, television tubes, electrical insulation
Alumino silicate glass	High-pressure mercury discharge tubes, chemical combustion tubes and domestic equipment
Silica glass	Chemical plants, laboratory crucibles, induction furnace lining and electrical insulators
Alkali-free glass	Thermal insulating material e.g. Glasswool, filtration of corrosive chemicals and sound insulation.

3.2.3 Refractory

Refractory are inorganic, non-metallic materials which can withstand at high temperature without undergoing physicochemical changes i.e. deformation in shape,while remaining in contact with molten slag, metal and gases.

(A) Composition of Refractories

Refractories are classified based on their chemical composition and physical shape such as acid refractory, basic refractory, neutral refractory and special refractory.

(B) Applications of Refractories

Depending upon the constituents, refractories are used composition, properties and uses of refractories, as shown in table 3.10

Table 3.10 Composition, Properties and Uses of Refractories

Items	Acid	Basic	Neutral	Special
Types of Refractories	a) Fire clay b) Silica c) High alumina	Magnesite Forsterite Magnesite-chrome Chrome-magnesite Dolomite	Carbon Graphite Silicon carbide Chromite	Single or Pure oxide : Pure Alumina, Magnesia Mixed Oxide : Mullite, Zircon Non oxide Insulating Monolithic
Composition	Fireclay, silica SiO_2, and alumino-silicate	CaO, MgO, dolomite and chrome-magnesite	Carbon, graphite, and silicon carbide, chromites	Alumina, Magnesia, zirconia, beryllia and thoria, silicon nitride, boron carbide, molybdenum disilicide, zirconium boride, titanium boride
Properties	Not affected by acidic materials	Attacked by acid slags	Chemically stable to both acids and bases.	Withstand very severe operating conditions Severe slagging occurs,
Uses	Masonry blast furnaces, hot blast stoves, glass kilns, rotary kilns, etc.	Open hearth furnaces, electric furnaces and mixed iron furnaces	Blast furnaces, hot blast stoves, refining outside the furnace and sliding nozzles, muffles	Nuclear and space research programme

3.2.4 Composite Materials

A **composite material** is a mixture of two or more micro constituents, which combine to give properties superior to those of the individual constituents.

Composite materials are excellent multiphase materials that find applications where very stringent and specific requirements are needed. Each class of basic engineering materials, e.g. metal, high polymers and ceramics, has its own outstanding and distinct and specific requirements are required.

(A) Constituents of Composites

Reinforced Cement Concrete (RCC) structure contain concrete, metallic rods and mixture of different materials. Concrete is good in compression but poor in tension, while metallic rods are good in tension but poor in compression. Concrete acts as matrix and reinforcement is provided by metallic rods.

(B) Classification of Composite

Composites are broadly classified as Natural composite and Synthetic composite.

- **Natural composite:** Wood is composite of cellulose fibers and lignin as cementing materials. Human or animal bone is a composite of soft and strong protein collagen and brittle and hard material apatite.
- **Synthetic Composite:** Based on types of matrix and reinforcement, they can be further classified as shown in table 3.11

Table 3.11 Composite Classification based on Types of Matrix and Reinforcement

Based on Matrix	Based on Reinforcement
Polymer matrix composite	Shape
Metal matrix composite	Orientation
Ceramic matrix composite	Properties

(C) Applications of Composites

- As composite materials are light in weight with high strength, they are used in the aerospace industry to prepare aircraft.
- These materials are also used in the preparation of automobile parts.
- Composite materials are used for medical assistance devices.
- They are used for the preparation of long tennis and hockey sticks.

3.3 POLYMERS

- **Polymer:** The polymer is a combination of two Greek words obtained by combining poly means many and mer means unit. The polymer may have a molecular weight in the range of 1000-10000000 μ (mu). For understanding the process of polymerisation, some of the basic terms are given below.
- **Monomer:** Single (identical or different) units that undergo repeated addition forming polymer.
- e.g. (1) Vinyl chlrode in PVC
  (2) Hexamehyelenediamine and adipic acid in Nylon 6:6.
- **Homomers :** Polymers that are derived from single monomers are known as homomers. e.g.PVC

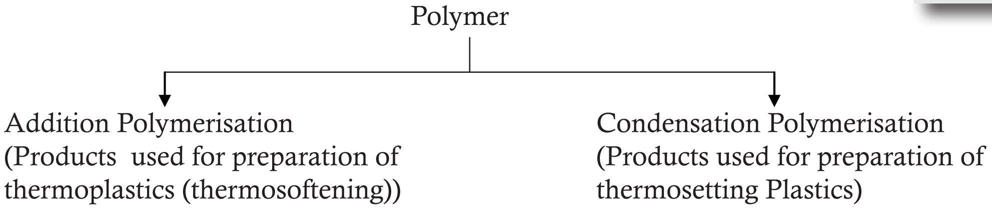
- **Co-polymer:** Polymers that are derived from two different monomers are known as co-polymers. e.g. Nylon 6:6.
- **Polymerisation:** It is the process of uniting or linking together monomer molecules to form a large polymer molecule under specific conditions of temperature, pressure, and catalyst known as polymerisation.
- **Degree of polymerisation:** It is the ratio of the average molecular weight of polymer to the weight of monomer.

$$\textbf{Degree of polymerisation} = \frac{\text{Average weight of polymer}}{\text{Weight of monomer}}$$

Polymers

Classification of Polymers

Polymers are divided as follows :



Polymer

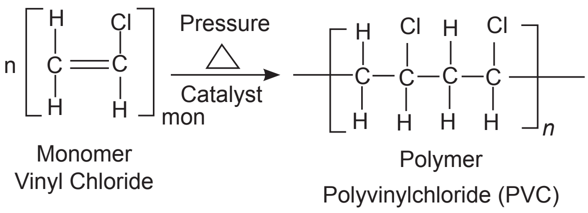
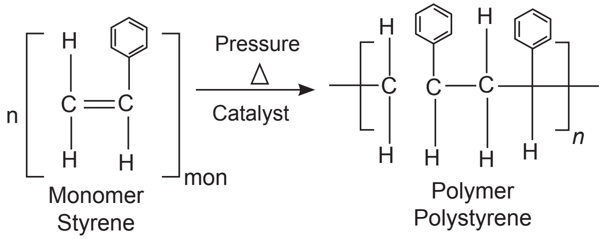
Addition Polymerisation
(Products used for preparation of
thermoplastics (thermosoftening))

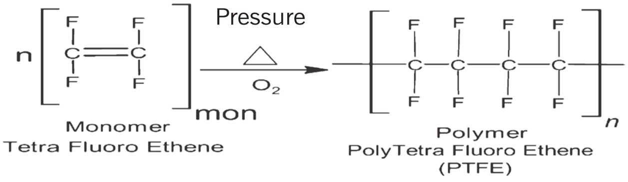
Condensation Polymerisation
(Products used for preparation of
thermosetting Plastics)

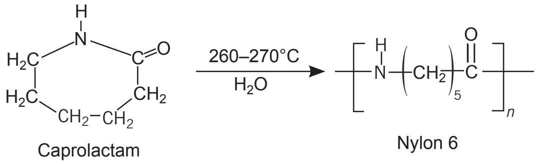
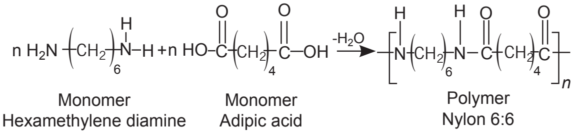
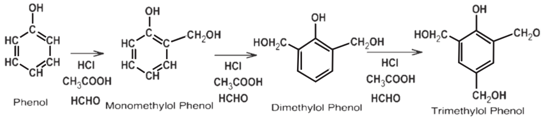
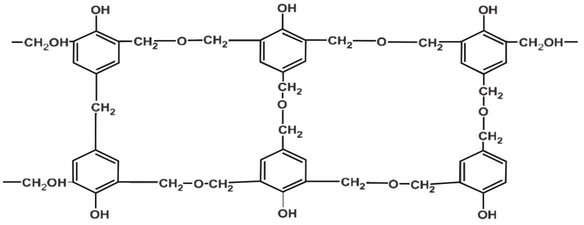
3.3.1 Preparation of Thermoplastic and Thermosetting Plastics

Thermosoftening plastics are the products of an addition polymerisation reaction, and thermosetting plastics are the products of condensation polymerisation reactions. Some of the reactions and their uses are given in table 3.12

Table 3.12 Polymerisation Reactions and their Uses

Polymers	Method of Preparation	Uses
Addition Polymerisation Reactions - Some Thermoplastics		
Poly Vinyl Chloride (PVC)		Window frames, drainage pipe, water service pipe, medical devices packaging, cling film, credit cards, vinyl records, synthetic leather and other coated fabrics
Poly Styrene (PS)		Food packaging, household appliances, consumer electronics products, building and construction, insulation foam, panels, bath and shower units, lighting, and plumbing fixtures. Medical items include tissue culture trays, test tubes, petri dishes, diagnostic components, and housing for test kits

Polymers	Method of Preparation	Uses
Addition Polymerisation Reactions - Some Thermoplastics		
Poly Tetra Fluoro Ethene (PTFE)		Non-stick cookware, containers and pipes anti-corrosive and non-reactive for Chemicals, lubricant for machinery, electrical appliances, dental industry for fillings to prevent them from sticking to adjacent teeth

Condensation Polymerisation Reaction - Some Thermosetting Plastics		
Nylon 6		Thread in the bristles of toothbrushes, surgical sutures, threads, rope, filament, nets, in hosiery and knitted garments
Nylon 6:6		Airbags, tyres, ropes, conveyor belts, parachutes, swimwear
Bakelite	 	High resistance to electricity and heat it is used to make switches and other electrical appliances, handle for iron and pans

Compounding of Plastics

Generally, plastics are compounded with other substances during their manufacturing process, which imparts specific, definite properties to their finished products.

(1) **Resins (Binders) :** These hold together the different constituents added during plastic preparation.

(2) **Fillers:** The substances which give better hardness, tensile strength, opacity, finish, workability. Fillers are of two types.

Organic filler : Wood flour, cotton, paper pulp, graphite, carbon black, powdered rubber

Inorganic filler : Asbestos, powdered mica, silicate, clays, talc, ZnO, PbO, BaS, CdS, and metals like Fe, Pb, Cu,and Al in powdered form.

(3) Plasticizer: These substances are added to increase the plasticity and flexibility of plastics

Camphor- It increases the surface hardness of plastic. Triacetin improves toughness

Tributyl and triphenyl phosphates are used for flame proofing.

(4) Catalyst or Accelerators: It accelerates the polymerisation of fusible plastic into cross-linked infusible form during moulding form. The catalyst used for compounding are H_2O_2, benzoyl peroxide, metals such as Pb, Ag, Cu, ZnO, ammonia etc.

(5) Colouring Matter Pigments: The colouring matter used in plastics should be resistant to the action of sunlight. Organic dyestuff and inorganic pigments are used as colouring materials.

Table 3.13 Difference between Thermoplastics and Thermosetting Plastics

Thermosoftening Plastics (Thermoplastics)	Thermosetting Plastics
These are the product of addition polymerisation reactions.	These are the products of the condensation polymerisation reaction.
Simple linear linkage with minimum or no cross-linking	Three-dimensional network-like structure.
It contains weak covalent bonds compared with bonds present in thermosetting plastics.	It contains a strong covalent bond compared with bonds present in thermoplastics
Soluble in an organic solvent	Insoluble in the organic solvent
These plastics are soft, weak and brittle.	These plastics are hard, strong and more brittle.
It can be heated and reshaped many times	It can be heated and shaped once.
Reclaimed from the waste	It cannot be reclaimed from the waste
Thermosoftening plastics have low molecular weight than thermosetting plastics.	Thermosetting plastics have high molecular weight than them softening plastics.
Ex. Polyethylene, PTFE, Polystyrene	Ex. Nylon 6:6, Bakelite

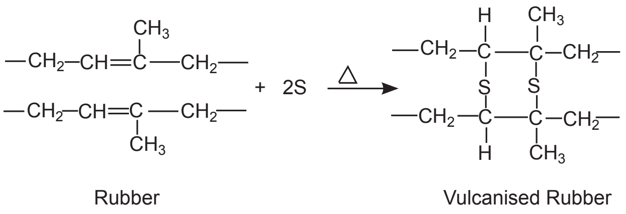
3.3.2 Rubber

Rubber is a substance that can be extracted naturally from trees or synthesised in laboratories which can be stretched in length after applying the force and regain its original shape and dimensions after removal of the force. This property of rubber is called elasticity

A rubber molecule is having a spring or coil-like nature. When force is applied, it gets converted into straight nature, and after removal of the force, it acquires its original spring-like nature.

3.3.3 Vulcanisation of Rubber

Natural rubber is soft in summer and hard in winter. Natural rubber absorbs water, soluble in organic solvents and undergoes oxidation. In the vulcanisation process, crude rubber is mixed with sulphur(S) or



hydrogen sulphide H_2S or benzoyl chloride or zinc oxide or stearic acid under high pressure at high temperatures up to 150^0C. The added sulphur reacts chemically at the double bond in rubber molecules of different rubber springs and preventing intermolecular movement or sliding. It also protects rubber from future deformation, vulcanised rubber won't deform as easily as conventional, non-vulcanised rubber. Rubber also becomes harder when vulcanised, which subsequently increases its tensile strength and reduces the risk of physical damage.

Table 3.14 Difference between Natural Rubber and Vulcanised Rubber

Natural Rubber	Vulcanised Rubber
Natural rubber is the latex of rubber trees that has a mixture of polymers	Vulcanised rubber is the material that forms after the vulcanisation of natural rubber.
A milky colloidal	A hardness rubber material containing cross-links between polymer chains
Less elastic	More elastic
Load-bearing capacity is low	High load-bearing capacity
Long isoprene chain only	It contains a long isoprene chain with a C-S-C chain across two different layers

Applications of Rubber

- Due to elasticity, strength and toughness, it is used for making rubber bands, tubes for bicycles, automobiles.
- Due to excellent abrasion resistance, used for making conveyor belts, shock absorbers mounting heavy machinery.
- Due to electrical resistance, rubbers are used for the insulation of wires, cables, electrical power transmission, plugs, sockets, battery cases.
- Due to chemical resistance, it is also used to make lined metal tank vessels used in the chemical industry. Due to chemical resistance to petrol, mineral oil and some solvents, rubber hose pipes are used for their transmission.

UNIT SUMMARY

- All the ores are minerals, but all the minerals are not ores
- General principles of metallurgy are-

  Crushing and grinding of the ore ,Concentration of the ore, extraction of metal from the concentrated ore, refining or purification of the impure metal.
- For concentration of the ore, gravity separation, froth flotation process magnetic separation methods are employed. Extraction of metal from the concentrated ore involves two steps i.e. conversion of the concentrated ore into its oxide and conversion of oxide to metal by the reduction process.
- Iron is extracted from haematite ore with different steps, including reduction of oxide ores in blast furnace.
- Extraction of aluminium is done from bauxite ore.
- Cement manufactured from chalk and clay which hardens under water and when hard resembles Portland stone in colour.

- Glass is an amorphous, hard brittle transparent or translucent or supercooled liquid of infinite viscocity having no definite melting point obtained by fusing a mixture of several metallic silicates or borates of sodium, potassium, calcium and lead.
- Refractory are inorganic non metallic materials which withstand at high temperature without undergoining physicochemical changes i.e. deformation in shape, while remaining in contact with molten slag, metal and gases.
- A **composite material** is a mixture of two or more micro constituents, which combine to give properties superior to those of the individual constituents.
- When monomer molecules undergo repeated addition in the presence of a temperature pressure catalyst to form a long chain, a high molecular weight compound, without eliminating simple molecules like water, ammonia and alcohol, is called an addition polymerisation reaction.
- When monomer molecules combine in the presence of temperature, pressure and catalyst to form a long chain, high molecular weight compound with the elimination of simple molecules like water, ammonia and alcohol, the process thus called condensation polymerisation reaction.
- Rubber is a substance that can be extracted naturally from trees or synthesised in laboratories. It can be stretched in length after applying the force and regain its original shape and dimensions after removal of the force.
- In the vulcanisation process, crude rubber is mixed with sulphur (S) or hydrogen sulphide H_2S or benzoyl chloride under high pressure at high temperatures up to 150°C.

EXERCISES

3.1 Write the chemical formula of the ores i) Dolomite ii) Mica iii) Haematite iv) Ruby Copper v) Bauxite vi) Corundum

3.2 List the various steps involved in metallurgical processes with their brief description.

3.3 Explain the various steps of extraction of metals from ore.

3.4 Describe electrolytic refining of copper for purification of metals.

3.5 Explain the aluminothermic process. Write the purpose of using the same.

3.6 Describe the smelting process carried out in blast furnace for extraction for iron from Haematite with the help of diagram.

3.7 Write the reactions taking place at different temperatures for reduction of iron oxide in blast furnace

3.8 Describe the Bayer's process for extraction of aluminium from bauxite.

3.9 List the purposes of alloying.

3.10 Write the Composition, properties and uses of following alloys of copper, iron, and aluminium. i) Brass ii) Aluminium bronze iii) Stainless steel iv) Chrome vanadium steel v) Duralumin vi) Nickeloy

3.11 Write the constituent composition of portland cement with their percentage.

3.12 Write the process of hardening of portland cement.

3.13 Write the different types of glasses and their uses in tabular form.

3.14 Differentiate the types of refractories on the basis of their composition, properties and uses.

3.15 Write the method of preparation, properties and uses of i) PVC ii) PS iii) Bakelite

3.16 Differentiate between thermoplastics and thermosetting plastics.

3.17 Write the process of vulcanization of rubber

PRACTICALS

1. PERCENTAGE OF IRON IN HAEMATITE

PRACTICAL STATEMENT

Determine the percentage of iron in haematite ore by standard $KMnO_4$ solution.

PRACTICAL SIGNIFICANCE

Diploma engineers have to work in metallurgical industries. They have to do analysis of the ores for identifying its metal composition for use in variety of applications, based on the properties of metals present. Determination of iron content in given ore using titration can be used in many industrial applications to solve broad based engineering problems.

RELEVANT THEORY

Haematite is an important ore of iron. For determination of iron in the given ore sample, the ore sample is dissolved in dilute HCl or dilute H_2SO_4. Iron is converted to ferric or ferrous salt solution with liberation of hydrogen gas. Reducing agents used for converting Fe^{3+} to Fe^{2+} are metallic zinc or stannous chloride. The Fe^{2+} present in the solution can be determined by titrating with standard $KMnO_4$ solution.

$$MnO_4^- + 8H^+ + Fe^{2+} \longrightarrow Mn^{2+} + Fe^{3+} + 4H_2O$$

PRACTICAL OUTCOMES (PrOs)

PrO1 Weigh accurately the given sample in electronic balance

PrO2 Prepare sample solution.

PrO3 Calculate the strength of a given acid or base using molarity equations.

CHEMICALS AND GLASSWARE REQUIRED

- **Chemicals** $KMnO_4$, dilute H_2SO_4, zinc granules, sample ore material, oxalic acid, HCl
- **Glassware** Burette (50 ml), pipette (10 ml), round bottom flask (250 ml), wire gauze, conical flask (100 ml), Volumetric flask (250 ml)

SAFETY PRECAUTIONS

1. Use mask, gloves and apron while working in the lab.
2. Handle the glasswares and chemicals carefully
3. Never spill chemicals inside the balance.
4. Cover the flask while heating.
5. Add solution drop wise from burette, with constant shaking of flask.
6. Place the conical flask on white tile to observe the colour change at the end point

SUGGESTED PROCEDURE

Part- A Preparation of Sample Solution

1. Weigh 1 g of ore and transfer it into 250 ml round bottom flask.
2. Add 100 ml of dilute H_2SO_4 into the round bottom flask and gently heat on wire gauze till the sample dissolve completely.
3. Add few granules of zinc when sample dissolves.
4. Cool it and transfer in to 250 ml volumetric flask, dilute the solution up to mark using distilled water.

Part- B Standardization of $KMnO_4$

1. Prepare 0.1 N $KMnO_4$ [refer preparation of normal solution, practical 1 of unit 1.
2. Pipette out 10 ml of 0.1N oxalic acid in conical flask.
3. Add 10 ml of dilute H_2SO_4 and heat the solution up to 70°C
4. Titrate the above solution against standard $KMnO_4$ solution till light pink colour appears
5. Repeat the procedure for three consecutive readings.

Part- C Determination of Percentage of Iron

1. Rinse and fill the burette with standard $KMnO_4$ solution.
2. Pipette out 10 ml of sample solution in conical flask. Add 10 ml of dilute H_2SO_4 solution
3. Titrate the above solution against standard $KMnO_4$ solution till light pink colour appears
4. Repeat the procedure for three consecutive reading.

OBSERVATIONS AND CALCULATIONS

Standardization of $KMnO_4$			Determination of % of Iron		
Sr.no	**Observation**	**Reading**	**Sr.no**	**Observation**	**Reading**
1	The solution in burette		1	The solution in burette	
2	Solution by pipette		2	Solution by pipette	
3	Indicator used		3	Indicator used	
4	Endpoint		4	Endpoint	

Table 1: Standardization of $KMnO_4$

Readings	Pilot Reading	1	2	3	V2=Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)					
Final Burette Reading (FBR)					
Difference (FBR-IBR)					

Table 2: Determination of Percentage of Iron

Readings	Pilot Reading	1	2	3	V3=Mean Difference =(1+2+3)/3
Initial Burette Reading					
Final Burette Reading					
Difference (FBR-IBR)					

Calculation

Standardization of $KMnO_4$

$N_1V_1 = N_2V_2$

N_1= Normality of oxalic acid 0.1N V_1= Volume of oxalic acid 10mL

N_2= Normality of $KMnO_4$ V_2= Volume of $KMnO_4$ from table 1

$$N_2 = \frac{\text{Normality of } KMnO_4 \times \text{Volume of oxalic acid}}{\text{Volume of } KMnO_4 \text{ from table 1}}$$

$$= \frac{0.1\times10}{\text{Concordant burette reading from table 1}} = \frac{1}{V_2} = \text{…………} = \text{…………}$$

Determination of Percentage of Iron

Step 1 1000mL 1N $KMnO_4 \equiv$ 56g of Fe

$$V_3 \text{ mL } N_2 \text{ N } KMnO_4 \equiv \frac{(56\times V_3 \times N_2)}{1000} \text{ of Fe} = \frac{(56\times\text{.......})}{1000} = \text{…………(y) g of Fe}$$

Step 2 10 mL of ore sample $\equiv$ y g of Fe

$$250\text{mL of ore sample} \equiv \frac{(y\times 250)}{10} = y \times 25 \text{ g of Fe} = \text{…………..}\times25= \text{………..(z)g Fe}$$

Step 3 1 g of Sample $\equiv$ (z)g Fe

$$100 \text{ g of sample} \equiv \frac{(z\times 1000)}{1} = \text{……….. g of Fe}$$

RESULTS AND/OR INTERPRETATION

Percentage of iron in haematite ore sample =……………….%

CONCLUSIONS AND/OR VALIDATION

(to be filled by student)

……………………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Write the procedure to dissolve Fe ore.
2. Name various ores of iron.
3. Mention the method of standarisation of $KMnO_4$.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin) ♻	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name……………………….........………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	% Weightage	Marks Obtained	Product Indicators (30%)	% Weightage	Marks Obtained	
Accuracy in weighing of sample	10		Viva-voce	10		
Preparation of solution and standarisation of $KMnO_4$	30		Report preparation	10		
Housekeeping	10		Calculations,results and interpretation	10		
Handling of glasswares	10					
Observance/ follow Safety precautions	10					

2. IODOMETRIC ESTIMATION OF COPPER

PRACTICAL STATEMENT

Estimate Iodometrically copper in the copper pyrite ore.

PRACTICAL SIGNIFICANCE

Diploma engineers have to perform in various metallurgical industries. They have to do analysis of ores to know the composition of metals to ensure quality and for their use in various applications. The determination of copper contents in given ore sample solution using iodometric estimation can be used to determine the strength of copper in various material and to solve the broad based engineering problems.

RELEVANT THEORY

Due to ductility, electrical and thermal conductivity, copper is used in production of electrical conductors, switches, transformers and telecommunications. Hence its extraction and percentage calculations plays a vital role. Copper can be estimated through iodometric titration in which oxidizing agents liberates iodine which is titrated with standard solution of reducing agent called as indirect or back titration. In this titration iodine is liberated by oxidizing agent Cu^{2+}, which is titrated against reducing agent sodium thiosulphate solution using starch as an indicator. The reaction between potassium iodide solution and potassium dichromate solution in acidic medium liberates iodine. Sodium thiosulphate solution (hypo solution) reduces liberated iodine to iodide

$K_2Cr_2O_7 + 6KI + 14\,HCl \longrightarrow 2CrCl_3 + 8KCl + 3I_2 + 7H_2O$
Orange Green

$Na_2S_2O_3 + 3I_2 \longrightarrow 3Na_2S_4O_6 + 6NaI$

$K_2Cr_2O_7 = 6Na_2S_2O_3$
Oxidising agent $K_2Cr_2O_7$
Reducing agent $Na_2S_2O_3 . 5H_2O$

$CuSO_4 + 4KI \longrightarrow Cu_2I_2 + 2K_4SO_4 + I_2$
Blue White ppt

$Na_2S_2O_3 + I_2 \longrightarrow Na_2S_4O_6 + 2NaI$

$2CuSO_4 \equiv 2Na_2S_2O_3$

Oxidising agent Cu^{2+}
Reducing agent $Na_2S_2O_3 . 5H_2O$

PRACTICAL OUTCOMES (PrOs)

PrO1 Apply the iodometric titration for estimation of copper.
PrO2 Prepare sample solution of copper
PrO3 Prepare 0.1 N sodium thiosulphate solution

CHEMICALS AND GLASSWARE REQUIRED

- **Chemicals (AR Grade)** Potassium dichromate($K_2Cr_2O_7$), sodium thiosulphate($Na_2S_2O_3$),
- **Glassware (Borosil)** Standard flask, funnel, wash bottle, beaker, dropper, spatula, standard flask

SAFETY PRECAUTIONS

1. Rinse and fill NaOH solution in the burette.
2. Remove the air gap present in the nozzle of the burette.
3. Fill the NaOH solution in the burette such that the lower meniscus should be at zero.
4. Do not keep the indicator open since it contains alcohol which tends to evaporate.
5. While handling chemicals and indicators, care should be taken so that it does not spill on to your skin .

SUGGESTED PROCEDURE

Preparation of Standard Copper Sample (Brass solution / Test solution)

1. Clean the glasswares thoroughly before use
2. Weigh 1 g of Copper sample, add to it 1:1 test solution of HNO_3 boil the mixture till brass dissolve completely.
3. Add 1 g of urea to expel the dissolved NO_2 completely. Boil till white vapors appears.
4. Add ammonia solution till deep blue colour appears.
5. Add acetic acid till light blue colour appears. It is added to neutralize acid. For liberation of iodine, slight acidic environment is required.
6. Transfer the reaction mixture in 250ml standard flask and dilute up to the mark.

Preparation of 250mL, 0.1N(0.1/6M) Potassium Dichromate Solution

Volume of Potassium dichromate solution (v) = 250mL

Strength of potassium dichromate solution M= 0.1/6 M

Molar Mass of potassium dichromate ($K_2Cr_2O_7$) =294 g mol^{-1}

Weigh of $K_2Cr_2O_7$ for the preparation of 250mL 0.1/6 M solution

$$= \frac{\text{Molarity} \times \text{Volume} \times \text{Molar mass}}{6 \times 1000} = 1.225\text{g}$$

1. Weigh out accurately 1.225g of potassium dichromate using electronic balance.
2. Transfer solid potassium dichromate in standard volumetric flask
3. Add about 100mL of distilled water and dissolve solid potassium dichromate.
4. Dilute the solution up to the mark i.e. to make it 250 ml.

Preparation of 0.1 N Sodium Thiosulphate Solution

1. Weigh out accurately 6.2 g of sodium thiosulphate
2. Transfer sodium thiosulphate in another 250 ml standard flask
3. Add about 100 ml of distilled water and dissolve solid sodium thiosulphate.
4. Dilute the solution upto the mark i.e. to make it 250ml.

Procedure

Step 1: Standardization of Potassium Dichromate Solution

1. Pipette out 20 ml of potassium dichromate solution into the conical flask.
2. Add 10 ml of 20% KI solution in the conical flask which contains potassium dichromate solution.
3. Add 5 ml of conc. HCl to same flask
4. Close the conical flask with watch glass and put the conical flask in dark place for 5 min.
5. Rinse and clean the burette with sodium thiosulphate solution (hypo solution)
6. Place conical flask in the dark and add 150 ml of distilled water.
7. Titrate this solution against sodium thiosulphate till it becomes pale yellow.
8. Add 2 ml of starch as an indicator.
9. Continue the titration till the solution becomes clear green.
10. Note down the reading (end point of titration)

Step 2: Determination of Percentage of Copper

1. Pipette out 20 ml of copper solution.
2. Add few drops of ammonia solution in copper solution till it becomes turbid (forms ppt)
3. Add few drops of acetic acid in copper solution till it dissolves all precipitate.
4. Add 10mL of 20% KI solution
5. Cover the conical flask with watch glass and put the conical flask in dark place for 5 min.
6. Add 100 ml of distilled water
7. Titrate this solution against sodium thiosulphate till it becomes pale yellow.
8. Add 2 ml of starch to pale yellow solution (colour changes from pale yellow to dark blue/ violet ppt)
9. Continue the titration with sodium thiosulphate till colour changes from dark blue to milky white solution
10. Add 20 ml 2% of sodium thiocyanate solution
11. Titrate this till it becomes white ppt.
12. Note the end point of titration.

OBSERVATIONS AND CALCULATIONS

Observation Table 1: Standardization of Potassium Dichromate Solution

Readings Pilot Reading	1	2	3	Vx=Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)				
Final Burette Reading (FBR)				
Difference (FBR-IBR)				

$1K_2Cr_2O_7 \equiv 6\,Na_2S_2O_3$ $M_1 = 0.1M$, $V_1 = 20mL$, $n_1 = 1$; $M_2 = ?$ $V_2 = V_x$, $n_2 = 6$

$$\frac{M_1V_1}{n_1} = \frac{M_2V_2}{n_2} =$$

$$M_2 = \frac{M_1 \times V_1 \times n_2}{n_1 \times n_2} = \frac{0.1 \times 20 \times 6}{6 \times \text{Burette reading } V_x} = \frac{2}{6 \times \text{Burette reading } V_x} = \frac{\dots\dots\dots}{\dots\dots\dots}$$

Molarity of hypo solution = (Mhypo) = …….. M

Observation Table 2: Determination of Percentage of Copper

Readings Pilot Reading	1	2	3	Vy=Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)				
Final Burette Reading (FBR)				
Difference (FBR-IBR)				

$2Na_2S_2O_3 = 2CuSO_4$

M_2= Mhypo, V_2= Constant burette reading (vy), $n_2 = 2$; $M_3 = ?$ $V_3 = 20mL$, $n_3 = 2$

$$\frac{M_2V_2}{n_2} = \frac{M_3V_3}{n_2}$$

$$\frac{M_2 \times V_2 \times n_2}{n_2 \times n_3} = \frac{\text{Mhypo} \times \text{burette reading (Vy)} \times n_3}{n_2 \times V_3}$$

$$= \frac{\text{Mhypo} \times \text{burette reading (Vy)} \times 2}{2 \times 20} = \frac{\dots\dots\dots}{\dots\dots\dots}$$

Molarity of copper Cu^{2+} solution = M_3 =……….M

$$\text{Amount of } Cu^{2+} \text{ in 100 mL solution} = \frac{M_3 \times \text{Atomic weight of copper} \times 100}{1000}$$

$$= \frac{M_3 \times 63.5 \times 100}{1000} = \frac{\dots\dots\dots}{\dots\dots\dots}$$

Amount of Cu^{2+} in 100 mL solution = z = M_3 ×6.35

1 g sample = z g Cu

100 g sample = z ×100 =………….. × 100 =………….

RESULTS AND/OR INTERPRETATION

Percentage of copper present in given sample is =………………%

CONCLUSIONS AND/OR VALIDATION

…..…………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Name the chemical which removes turbidity formed due to addition of ammonia in sample solution.
2. State the colour when iodine is liberated with addition of KI to ore sample.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin) ♻	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

4.15 SUGGESTED ASSESSMENT SCHEME

Student's Name……………………..........……………………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	% Weightage	Marks Obtained	Product Indicators (30%)	% Weightage	Marks Obtained	
Accuracy in preparation of solution	15		Viva-voce	10		
Titration process and identification of endpoint	20		Report Preparation	10		
Housekeeping	10		Calculations,results & Interpretation	10		

Handling of glasswares	15					
Observance/ follow safety rules	10					

3. IRON CONTENTS IN CEMENT USING COLORIMETER

PRACTICAL STATEMENT

Determine the Iron contents in given cement sample using colorimeter.

PRACTICAL SIGNIFICANCE

Cement is a very important building material with excellent binding properties. Almost every construction work requires cement hence knowing its composition is of great interest and importance to engineers and technologists. Knowing the functionality of cement ingredients is very important. By altering the amount of an ingredient during cement production, one can achieve the desired cement quality. Iron is an important element to the human body. It is found in the oxygen-delivering protein, hemoglobin. Iron contents in cement imparts color to it. It also acts as a flux. At a very high temperature, it forms tricalcium alumino-ferrite. With calcium and aluminum it imparts hardness and strength to cement. Hence determining the iron contents in cement is of utmost importance.

RELEVANT THEORY

Colorimetry is the technique used to find the concentration of substance in coloured solution using instruments such as photo colorimeter or spectrophotometer.Principle behind this experiment is based on the Lambert Beer's Law. The basis of spectrophotometric methods is the simple relationship between the absorption of radiation by the solution and the concentration of species in the solution. Whenever the monochromatic light (light of single wavelength) is passed into a coloured solution, some amount of the radiation is absorbed and remaining is transmitted. 'I_0' indicates intensity of incident radiation and 'I' indicates intensity of transmitted radiations. C is the concentration of solution and L is the path length of the cuvettes. When monochromatic light is passed through coloured solution the absorption takes place in the visible region. The absorption increases with the concentration, while transmission decreases due to increase in the concentration. When path length increases the absorption also increases.

PRACTICAL OUTCOMES (PrOs)

PrO1	Weigh accurately the given sample in electronic balance.
PrO2	Prepare standard solution of given sample of defined molarity and normality.
PrO3	Determine the iron contents in cement and other unknown samples using spectrophotometer.
PrO4	Identify the concentration of iron graphically.

PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)

The colorimeter consisting of a light source (lamp), filter, cuvette and photosensitive detector to measure incident and transmitted light.. A colorimeter contains a photocell which is able to detect the amount of light passing through the solution under investigation. The current produced by the photocell depends on the quantity of light hitting it after passing through the coloured solution. The higher the concentration of the colorant in the solution, the higher is the absorption of light; less light passing through the solution means less current created by the photocell.

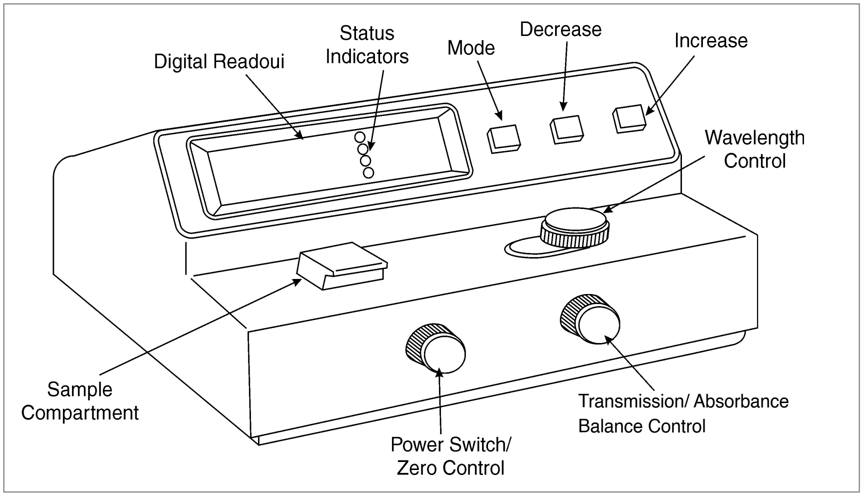


Fig. Key Operating Features of Colorimeter

RESOURCES, CHEMICALS AND GLASSWARE REQUIRED

- **Resources** Photo colorimeter (wavelength accuracy ±0.9nm)
- **Chemicals (AR Grade)** Cement sample, ferrous ammonium sulphate, 40% potassium thiocyanate, 40% ammonium thiocyanate, conc. H_2SO_4, dil HCl, $KMnO_4$, HNO_3 sample and cement sample.
- **Glasswares (Borosil)** Standard volumetric flask (100mL), beaker (100/250/500mL), burette, pipette.

SAFETY PRECAUTIONS

1. Spectrophotometer is switched on and warmed up for 10 min.
2. Monochromator is adjusted to 480 nm.
3. After taking absorption, wash the cuvette with distilled water.

SUGGESTED PROCEDURE

Preparation of Stock Solution

1. Measure 0.083 g ferrous ammonium sulphate (FAS).
2. Add 1mL conc. HNO_3 in FAS which converts Fe^{2+} to Fe^{3+}
3. Dilute the mixture using 1L of distilled water. This is the stock solution.
4. Mix stock solution, ammonium thiocyanate (for development of colour) and distilled water as per observation table.

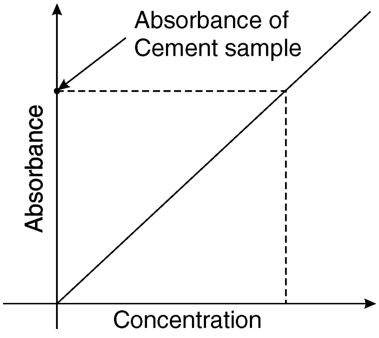
Procedure for Preparation of Cement Solution

1. Weigh accurately about 0.1 g of the given cement sample into a clean 250 ml beaker.

2. Add about 5 ml water to sample. Mix well and then add 1-2 mL concentrated HCl. Again mix well.
3. Evaporate the mixture to dryness, expel the excess acid.
4. Add 20 mL of distilled water to dissolve the contents and transfer all contents into standard volumetric flask (100 mL).
5. Dilute the solution with distilled water up to the mark.
6. Shake well for uniform concentration.
7. Pipette out 10 ml of above solution, into 100 ml standard flask
8. Add 1 ml of conc. HNO_3 and then add 5 ml of 40% NH_4SCN with a burette. Make up the solution up to the mark with distilled water.

Procedure to Record Absorbance

1. Blank solution with water and ammonium thiocyanate is mixed and kept in the cell. The absorption is measured for which absorption is zero and transmittance is 100 %.
2. Now absorbance of all prepared standard solution is similarly measured in increasing order of concentration.
3. Finally take the absorbance of the sample solution into colorimeter tube and measure the absorbance using the photo colorimeter.
4. Plot graph of absorbance (y-axis) vs concentration (x-axis).
5. From the absorbance value we can measure the concentration of Fe^{2+} from the calibration curve.



Graph

OBSERVATIONS AND CALCULATIONS

Sr. No	Volume of FAS Stock Solution	Volume of Ammonium Thiocyanate	Volume of Distilled Water	Concentration of Fe^{3+} in ppm	Observed Absorbance
1	0	5	5	---	
2	1	1	8	1	
3	2	2	6	2	
4	3	3	4	3	
5	4	4	2	4	
6	5	5	0	5	
7	Cement Solution				

RESULTS AND/OR INTERPRETATION

1. Concentration of unknown cement sample from graph is = ...

CONCLUSIONS AND/OR VALIDATION

....

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Write the relation between absorption and concentration.
2. Mention the role of iron supplements in the human body

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name…………………………………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	% Weightage	Marks Obtained	Product Indicators (30%)	% Weightage	Marks Obtained	
Accuracy in weighing of sample	10		Viva-Voce	10		
Preparation of solution	10		Report preparation	10		
Housekeeping	10		Calculations,results and interpretation of graph	10		
Use of spectro-photometer & determining the iron contents	30					
Observance/ follow safety Precautions	10					

KNOW MORE

- Different types of furnaces used in metallurgy such as reverberatory furnace, bessemer converter, electric furnace, muffle furnace.
- Beneficiation : Industrial processes that extract the desired commodity from a rock and/ or mineral.
- Exothermic reactions and endothermic reactions.
- Spalling of a refractory: Fracture due to uneven expansion at high temperature. Refractory masonary materials may fail prematurely due to thermal shock or excessive temperatures, mechanical damage or improper installation.
- Mechanism of addition and condensation polymerisation reaction.
- Properties of rubber like, hardness, tensile strength, rebound and tack.

Suggestive Micro Projects / Activities

- Explore and collect some samples of ores from different natural sources by digging the reasonably good size of sample ore. Based on your learning from this unit, purify the ore by using the most convenient method, you can adopt. Prepare a report and present the same in the class.
- Collect different polymers and prepare the chart/ power point based on their type, properties and uses.

Inquisitiveness and Curiosity

We have abundant rich natural ores and mineral resources in our country. In spite of that the metallic items produced for household applications/purposes for the average mass of people are not of good quality and develop cracks over the period of time.

REFERENCES AND SUGGESTED READINGS

- Shikha Agarwal, Engineering Chemistry, Cambridge University Press; New Delhi,2015. ISBN, 978-1-107-47641-7
- C.N.R.Rao, UnderstandingChemistry, Universities Press (India) Pvt. Ltd.,2011, ISBN 8173712506
- Dara, S. S. & Dr. S. S. Umare, Engineering Chemistry, Universities Press (India) Pvt.Ltd., 2011, ISBN, 8121903599
- Jain & Jain, Engineering Chemistry, Dhanpat RaiandSons; New Delhi, 2015, ISBN 8187433175
- Dr. G. H Hugar & Prof. A. N. Pathak, Vol. land Vol. II, NITTTR Chandigarh, Publications, 2013-14.

4 Chemistry of Fuels and Lubricants

UNIT SPECIFICS

This unit comprises of the following major topics:

- Fuel and Combustion of Fuel
- Analysis of Coal
- Lubrication
- Functions of Lubricants
- Characteristic Properties of Good Lubricants
- Classification of Lubricants
- Mechanism of Lubrication
- Physical Properties of Lubricants
- Chemical Properties of Lubricants

The different concepts have been explained through examples for generating further curiosity and inquisitiveness and also developing creative problem solving abilities in the students, with the mention of their practical applications in the industries/day to day life.

Assessment for learning at different intervals within the unit, at different levels of cognitive domain is carried out by designing formative assessment questions.

For effective implementation of the outcome based curriculum in true spirit, wide spectrum of activities such as micro projects, assignments, industrial visits etc, are designed and integrated in the unit for the benefit and exposure of the students. Sample QR codes have been provided on various topics/sub topics for supplementary reading and reinforcing the learning.

RATIONALE

Rapid growth, industrialization and technological development has led to focus on urgent need of producing heat, power and energy is one of the major engineering challenge today. The world's energy demand is constantly increasing. The fossil fuel has made possible many of the necessities and convenience of the modern society. Non-renewable energy resources include coal, natural gas, oil, and nuclear energy. Once these resources are used up, they cannot be replaced, which is a major problem for humanity as we are currently dependent on them to supply most of our energy needs. Looking to this scenario, we have to develop the mechanism to produce the fuels from other sources such as crops and use it as a substituent for gasoline. Hence we can produce ethanol, biogas etc to decrease the use of non-renewable fuels which helps to reduce the pollution.

Lubricants are regarded as the lifeblood of machinery. Lubricants are an essential component across multiple industrial activities. From bearings to engines to hydraulics, they are used to keep industries running smoothly.

PRE-REQUISITES

Chemistry	:	States of matter, engineering materials
Mathematics	:	Basic algebra and geometry

UNIT OUTCOMES

List of outcomes of this unit are as follows :

U4- O1	Determine proximate analysis of coal for assessing its quality for domestic and industrial use.
U4- O2	Assess the efficiency of coal by determining the calorific value of fuel.
U4- O3	Use different gaseous fuel based on their composition, calorific value and other properties.
U4- O4	Select relevant lubricant based on the function and characteristic properties and for use in different kinds of machinery.
U4- O5	Determine viscosity, flash and fire point of given lubricant for its specific use.

Unit - 4 Outcomes	Expected Mapping of Unit Outcomes with the Course Outcomes (1- Weak Correlation; 2- Medium Correlation; 3- Strong Correlation)				
	CO-1	CO-2	CO-3	CO-4	CO-5
U4-O1	-	-	-	3	-
U4-O2	-	-	-	3	-
U4-O3	-	-	-	3	-
U4-O4		-	1	3	2
U4-O5	-	-	1	3	2

4.1 FUELS AND COMBUSTION OF FUELS - AN INTRODUCTION

Industries require power for their routine operations. Heat energy is the primary source of power. These are combustible substances, & the heat produced by burning of fuels can be utilised economically, both for industrial and domestic purposes and to meet these expanding requirements, we should look for various kinds of fuels. The present unit is focused on the study of fuels and lubricants.

4.1.1 Fuels and its Combustion

Fuel is a combustible substance, containing carbon as main constituent, which on proper burning gives large amount of heat and can be used economically for domestic and industrial purpose.

E.g. Wood, coal, kerosene oil, gasoline, liquefied petroleum gas (LPG), petrol, diesel, hydrogen gas, ethanol etc. During the process of combustion of fuel, the atoms of carbon, hydrogen etc. combine with oxygen with the simultaneous liberation of heat at rapid rate. This energy is liberated due to the rearrangement of valence electrons in these atoms, resulting in the formation of new compounds.

$$\text{Fuel + Oxygen} \xrightarrow{\hspace{2cm}} \text{Product/s + Heat}$$

$C + O_2 \longrightarrow CO_2$ + Heat released $\Delta H = -\ 94.1$ Kcal/mole

$2H_2 + O_2 \longrightarrow 2\ H_2O$ + Heat released $\Delta H = -\ 67$ Kcal/mole

These new compounds have less energy and, therefore the energy released during the combustion process is the difference in the energy of reactants and that of the product formed.

Combustion of fuel : It is a temperature rising exothermic reaction between a fuel and oxygen.

4.1.2 Classification of Fuels

Classification of fuel, based on their physical state and source, from which they are obtained,are as shown in table 4.1

Table 4.1 : Classification of Fuels

Physical State	Natural Sources of Fuels	Man Made Sources of Fuels
Solid Fuels	Wood, coal, peat, lignite, bituminous, anthracite, oil-shale, tar, sand, dung	Wood-charcoal, coke, semi-coke, petroleum coke, pulverised coke, colloidal fuels, thiokol, hydrazine, nitrocellulose, coal briquette etc.
Liquid Fuels	Crude oil or petroleum, natural gasoline	Petrol, gasoline, diesel oil, gas oil, kerosene, oil, coal tar, alcohols, synthetic spirits etc.
Gaseous Fuels	Natural gas	Coal gas, coke oven gas, water gas, producer gas, carburetted water gas, oil gas, biogas, blast furnace gas, refinery oil gas, synthesis gas, acetylene and liquid petroleum gas, hydrogen gas etc.

4.1.3 Calorific Values

The calorific value of fuel is its essential property, which supplies heat. The amount of heat supplied by a definite quantity of fuel varies from fuel to fuel. Calorific value helps to assess the efficiency of the fuel.

The calorific value of fuel is the amount of heat obtained by complete combustion of unit mass of fuel.

Calorific values of solid and liquid fuels are usually expressed in calories per gram(Cals/g) or Kilocalories per kilogram(K cals/kg) or British thermal units per pound (B.Th.U./lb), whereas the calorific values of gases are expressed as Kilocalories per cubic meter (K cal/m^3) or British thermal units per cubic foot (B.Th.U/ft^3) or Centigrade heat unit per pound (C.H.U./lb) or Centigrade heat unit per cubic foot C.H.U./ft^3

These units can be interconverted as follows

1 K cal/Kg=1.8B.Th.U./lb

1 Kcal/m^3 =0.1077 B.Th.U/ft^3

1 B.TH.U/ft^3 =9.3 Kcals/m^3

(A) Higher Calorific Value (HCV) or Gross Calorific Value

Usually, all fuel contains some hydrogen and when the calorific value of hydrogen- containing fuel is determined experimentally, the hydrogen is converted into steam. If the products of combustion are condensed to room temperature, the latent heat of condensation of steam also get included in the measured heat, which is called higher or gross calorific value. So the gross or higher calorific value is

HCV It is the total heat generated when a unit quantity of fuel is completely burnt and the products of combustion are cooled down to 15^0C

(B) Lower Calorific Value (LCV) or Net Calorific Value

In actual use of any fuel, the water vapour and moisture, etc., are not condensed and escape as such along- with hot combustion gases. Hence a lesser amount of heat is available. So net or lower calorific value is

LCV It is the net heat produced when a unit quantity of fuel is completely burnt and the products of combustion are allowed to escape.

Net or lower calorific value (LCV) =HCV– Latent heat of water vapour formed. We will be learning about the determination of the calorific value of solid or liquid fuel using a bomb calorimeter through practial performance is mentioned at the the end of the unit.

4.1.4 Calculation of HCV and LCV using Dulong's Formula

The calorific value of fuel can be approximately computed by noting the amounts of the fuel constituents. The higher calorific values of some of the chief combustible constituents of fuel are given in table 4.2

Table 4.2 Higher Calorific Values of Fuel Constituents

Constituents	Hydrogen	Carbon	Sulphur
HCV (kcal/kg)	34500	8080	2240

The oxygen is present in the fuel and is assumed to be present in a combined form with hydrogen, i.e., fixed hydrogen [H_2O].

So, the amount of H available for combustion. = Total mass of H in fuel – Fixed H

Since 8 part of oxygen combines with one part of hydrogen to form H_2O

= Total mass of hydrogen in fuel $-\frac{1}{8}$ mass of oxygen in the fuel

Dulong's formula for higher calorific values (HCV) from the chemical composition of fuel is

$$\text{HCV} = \frac{1}{100}\left[8080C + 34500\left(H - \frac{O}{8}\right) + 2240S\right] \text{Kcal/kg}$$

Where C, H, O and S are the percentage of carbon, hydrogen, oxygen and sulphur in the fuel, respectively. In this formula, oxygen is assumed to be present in combustion with hydrogen as water, this is based on the fact that one part of H by mass gives nine parts of H_2O

$$\begin{array}{llll} H_2 & + & O \longrightarrow & H_2O \\ 2g & & 16g & 18g \\ 1g & & 8g & 9g \end{array}$$

LCV = HCV– Latent heat of condensation of the water vapour produced

= HCV– (Mass of H per unit weight of the fuel burnt × 9 × latent heat of vapourisation of water

Latent heat of steam is 587 Kcal/kg

Dulong's formula for lower calorific values (LCV) from the chemical composition of fuel is

$$\text{LCV} = \left[\text{HCV} - \frac{\text{H}}{100}\,9 \times 587\right] \text{Kcal/kg}$$

$$\text{LCV} = \text{HCV} - 0.09\text{H} \times 587 \text{ Kcal/kg}$$

Where H = % of hydrogen in the fuel.

In actual practical use of fuel, it is rarely feasible to cool the combustion products to room temperature to allow the combustion of water vapour formed and utilise that latent heat. Hence the water vapour created also is allowed to escape along with the hot combustion gases.

4.2 ANALYSIS OF COAL

4.2.1 Proximate Analysis of Coal (Solid Fuel)

The composition of coal varies with mines, hence, it is necessary to analyse the quality of coal, which helps commercial classification, price fixation, and industrial utilisation. Proximate analysis of coal involves the determination of moisture, volatile matter, ash and fixed carbon. The proximate analysis gives information about the practical utility of coal.

1. **Determination of Moisture :** Weigh about 1 g of finely powdered air-dried coal sample in a silica crucible with a lid. The crucible is placed inside the electric hot-air oven, maintained between 105^0-110^0 C. The crucible is allowed to remain in the oven for about an hour, and then taken out with the help of pair of tongs, cooled in a desiccator and weighed. By knowing the loss in weight of coal, the percentage of moisture can be calculated as :

   $$\% \text{ of Moisture} = \frac{\text{Loss in weight of coal}}{\text{Weight of coal taken}} \times 100$$

   Moisture increases the transport cost and also reduces the effective calorific values of coal. Much amount of heat is wasted in evaporating the moisture available in coal during combustion. The lesser the moisture content, the better is the quality of coal as fuel. Hence high percentage of moisture is undesirable.

2. **Determination of Volatile Matter:** The dried sample of coal left in the crucible (in stage 1, i.e. determination of moisture) is then covered with a lid and placed in an electric muffle furnace maintained at 925^0C. The heating is carried out for 7 minutes. The hot crucible is then taken out and cooled first in the air, then inside a desiccator and weighed again. Loss in weight is reported as volatile matter on percentage basis. By knowing the weight of volatile matter removed from coal, its percentage can be calculated as

   $$\% \text{ of Volatile Matter } = \frac{\text{Loss in weight due to removal of volatile matter}}{\text{Weight of coal taken}} \times 100$$

   Volatile matter is not a constituent of coal but consists of a complex mixture of gaseous and liquid products resulting from the thermal decomposition of the coal substance. Hence stipulated conditions should be followed during its determination. Thus, the greater the volatile matter lowers the calorific value, and the lesser the volatile matter, the better is the rank of coal.

3. **Determination of Ash :** The residual coal in the crucible (in stage 2 i.e. determination of volatile matter) is then heated in an open crucible (without lid i.e. in the presence of oxygen of air) at 750^0C for half hour in a muffle furnace. Here the coal is converted into ash by burning in the air. The crucible is taken out, cooled first in the air, then in desiccator and weighed. Heating, cooling and weighing is repeated till constant weight is obtained.

The residue produced is reported as ash on percentage basis.
By knowing the weight of ash formed, its percentage can be calculated as

$$\% \text{ Ash} = \frac{\text{Weight of ash left}}{\text{Weight of dry coal taken}} \times 100$$

Chemistry of Coal

Ash is useless, non-combustible matter, which reduces the calorific value of coal. Moreover, ash causes the hinderance to the flow of air and heat, thereby lowering the temperature. The presence of ash also increases transporting, handling and storage costs. It also involves additional cost in ash disposal. Hence the formation of ash by burning coal is undesirable. The lower the ash content, the better is the quality of coal.

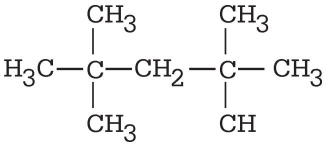
4. **Determination of Fixed Carbon :** It is determined indirectly by deducting the total of percentage of moisture, volatile matter and ash from 100. It gives the percentage of fixed carbon.
   % of fixed carbon =100 - % of moisture + % of volatile matter + % of ash

   Higher the percentage of fixed carbon, greater is its calorific and better the quality of coal. Greater the percentage of fixed carbon, smaller is the percentage of volatile matter. Hence high percentage of fixed carbon is desirable. We will be learning about the determination of moisture and ash content in a given coal sample using proximate analysis through practical performances in the lab mentioned at the end of this unit.

4.2.2 Fuel Rating of Petrol and Diesel (Octane & Cetane numbers)

Octane Number : In an internal combustion engine, a mixture of gasoline (petrol) vapour and air is used as a fuel. After the initiation of the combustion reaction, by a spark in the cylinder, the flame should be spread rapidly and smoothly through the gaseous mixture, thereby expanding gas which drives the piston down the cylinder. The ratio of the gaseous volume in the cylinder at the end of the suction stroke to the volume at the end of compression stroke of piston is known as compression ratio. The efficiency of an internal combustion (IC) engine increases with the increase in the compression ratio, which is dependent on the nature of the constituent present in the gasoline used. In certain situations, the oxidation rate becomes so great that the last portion of the fuel-air mixture ignites instantaneously, producing explosive known as knocking.

This means during compression of piston, pre-ignition of the explosive mixture, started combusting spontaneously just before the spark. The knocking results in pinging or detonating sound which is arising due to uneven combustion of fuel inside the engine and also results in loss of efficiency. Glowing spark plug tip can also be reason for pre ignition. To prevent pre ignition spark plug should be carefully matched to the recommended heat range.It has been found that n-heptane knocks very badly, its anti-knock value has arbitrary been given zero and iso-octane gives very little knocking, so its anti-knock value has been given as 100.



$$H_3C-\underset{CH_3}{\overset{CH_3}{C}}-CH_2-\underset{CH}{\overset{CH_3}{C}}-CH_3$$

iso-octane
Octane No. =100

$$H_3C-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$$

n-heptane
Octane No. = 0

The octane number of gasoline is the percentage of iso-octane in a mixture of iso-octane and n-heptane which just matches with the knocking characteristics of the fuel under consideration

Table 4.3 Octane Rating of some Common Hydrocarbon

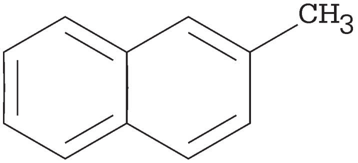
Hydrocarbon	Octane Number
Benzene	100+
Isopentane	90
Cyclohexane	77
2-methyl pentane	71
n-pentane	62
n-hexane	26

For determining the octane rating, the fuel is tested for knocking and octane number of particular mixture of iso-octane and n-heptane that produces same amount of knock at similar conditions assigned to it. e.g. fuel of octane number 80 and fuel mixture of 80% iso octane and 20% n-heptane produces same amount of knock.

The higher the octane number, the more compression from the piston, and the gasoline can withstand before igniting in the engine. This means higher the octane number lesser is the knocking. The octane number of gasoline may be increased by the addition of fuels of higher knock value. The anti knock properties of gasoline are usually enhanced by adding tetra ethyl lead (TEL) [$Pb(C_2H_5)_4$] and the process is called as doping. TEL greatly diminishes the knocking tendency of any hydrocarbon with which it is mixed. The addition of a small amount of TEL to a gasoline of low antiknock values usually increases the octane number to a very considerable extent. About 0.5mL of tetra ethyl lead per litre is added for motor spirits and about 1 mL TEL per litre is generally added to aviation petrol. The octane rating of some common hydrocarbons are given in table 4.3

Cetane Number : The knocking characteristics of diesel oil are expressed in terms of cetane number. Cetane[$C_{16}H_{34}$] is a saturated hydrocarbon with a very short ignition lag than any commercial diesel fuel. Hence its cetane rating is taken as 100. On the contrary, methyl naphthalene [$C_{11}H_{10}$], a aromatic hydrocarbon has very long ignition lag as compared to any commercial diesel oil. Hence cetane rating is taken as zero.

Cetane number is the ignition value of diesel fuel that represents the percentage by volume of cetane in cetane and liquid α -methylnaphthalene mixture,which exactly matches in its knocking characteristics with oil under test.



α methyl naphthalene
(Cetane No.=0)

$$H_3C - (CH_2)_{14} - CH_3$$

Cetane or n-Hexadecane
(Cetane No.=100)

Cetane number is given by testing a fuel and providing a rating of the mixture of cetane and 2-methyl naphthalene which produces the same amount of knock at similar conditions.

In high speed diesel engine, the time lag in getting the diesel droplets heated to ignition point is very small, about 1/500th of second. Such diesel engines require diesel with cetane numbers greater than 45. On other hand, low speed diesel requires cetane number of about 25.

The cetane number of oil can be improved by adding substances called dopes. eg. ethyl nitrile, ethyl nitrate, isoamyl nitrate and acetone peroxide. The dopes are added only in small amounts and they are not effective on low cetane number fuels. Use of dopes for diesel oil is not as common as the use of TEL for gasoline.

In petrol engines knocking is due to the spontaneous combustion of the last portions of the fuel, whereas knocking in a diesel engine is due to delay in the spontaneous combustion of the first part of the fuel. Thus oil of high octane number has low cetane number and vice- versa. Furthermore, a crude oil which gives petrol of high octane number gives a diesel oil of low cetane number.

Overall octane rating represents how much compression fuel can withstand without ignition whereas cetane rating represents how fast the fuel can be ignited.

SAQ 1	Octane number of iso-octane is			
	1) 0	2) 100	3) 50	4) 30

Key: 2

4.2.3 Chemical Composition, Calorific Values and Applications of Fuels

Composition, calorific values and applications of some fuels are given in table 4.4

Table 4.4 Composition, Calorific Values and Applications of Fuels

Fuels	Composition	Calorific Values	Applications
Liquefied Petroleum Gas (LPG)	Propane, n-butane, isobutane, propylene, butylene, Small quantity of ethane, pentane, ethylene and pentene may also present	11,850 Kcal/kg	Domestic fuel, industrial fuel,heating appliances and vehicles, motor fuel in internal combustion engine (IC-engine)
Compressed Natural Gas (CNG)	95% methane, 4% nitrogen and ethane, 1% carbon dioxide and propane	12,600 Kcal/kg	Automotive fuel
Water Gas (Blue Gas)	Carbon monoxide, hydrogen	2670 Kcal/m^3	Synthesis of ammonia, methyl alcohol illuminating gas, heating and lightning purpose, welding purpose.
Coal Gas	Hydrogen, methane, ethylene, acetylene, carbon monoxide, nitrogen	4500- Kcal/m^3	Lighting, heating, fuel for cooking, illuminant
Producer Gas	Carbon monoxide, nitrogen	1300 Kcal/m^3	Heating open hearth furnace, in muffle furnace, reducing agent in metallurgical operations
Biogas	Methane, carbon dioxide, hydrogen, nitrogen.	5300 Kcal/m^3	Domestic fuel, lightning, water pumps, cutting machine

Interesting Fact : CNG has a higher flash point [the temperature at which the fuel is likely to explode on its own] of 540^0C than petrol (flash point of 232^0C-282^0C)

4.3 LUBRICATION AN INTRODUCTION

In all types of machines, the surfaces of moving metals or sliding or rolling parts rub against each other. Due to the mutual rubbing of one part against another, a resistance is offered to their movement.

Any substance introduced between the two moving/sliding surfaces with a view to reduce the friction or frictional resistance between them, is known as **lubricant.**

This resistance is known as friction. It causes a lot of wear & tear of surfaces of moving parts.

Due to friction, large amount of energy is liberated in the form of heat which reduces the efficiency of machine.The main purpose of a lubricant is to keep the moving/sliding surfaces apart, so that friction and consequent destruction of material is minimised

The process of reducing friction between moving/sliding surfaces, by the introduction of lubricants in between them, is called **lubrication.**

Either oil or grease is used for rolling bearings to prevent noise, wear, tear and heat from being generated from their rolling and sliding movements. In some special cases, solid lubricants are used. The amount and kinds of lubricants for rolling bearings are determined depending on operation speed, temperature, surrounding condition etc. Lubricants have to be periodically replaced or oiled.

4.4 FUNCTIONS OF LUBRICANTS

The main functions of lubricants are as follows

- prevent overheating of bearings and to prevent lubricants, deterioration by radiating the generated heat to outside.
- prevent foreign material penetration, rust, and corrosion.
- reduce wear and tear of the surfaces by avoiding direct metal to metal contact between the rubbing surfaces, i.e. by introducing lubricants between the two surfaces.
- reduce expansion of metal due to frictional heat and destruction of material.
- as coolant of metal due to heat transfer media.
- avoid unsmooth relative motion.
- reduce maintenance cost.
- reduce power loss in internal combustion engine.
- reduce the friction between two moving surface.
- rust and corrosion inhibitors.

Application of Lubricants

Lubricants are used in

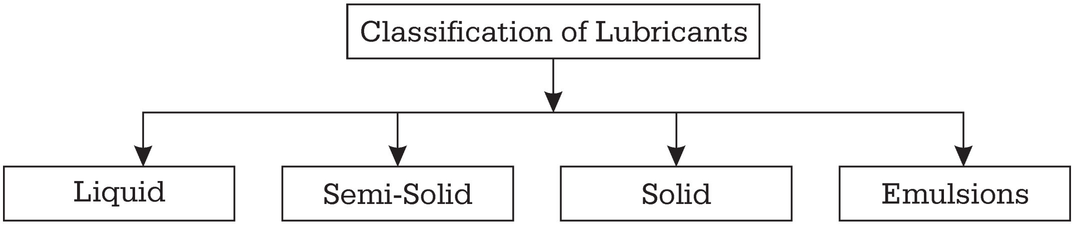
- the soap and paint industries.
- medicines.
- cutting fluid in cutting, grinding, drilling of metals.
- anti-wear, antioxidants, and antifoaming agents.

4.5 CHARACTERISTIC PROPERTIES OF GOOD LUBRICANTS

Good lubricants should have -

- high boiling point
- low freezing point
- adequate viscosity for proper functioning
- high resistance to oxidation and heat
- non-corrosive properties
- stability to decomposition at the operating temperatures
- high viscosity index
- higher flash and fire points than the operating temperature of the machine
- high oiliness
- lower cloud and pour points than the operating temperature of the machine
- low volatility.
- deposit least amount of carbon during use
- higher aniline point.
- higher resistance towards oxidation.
- good detergent quality

4.6 CLASSIFICATION OF LUBRICANTS



4.6.1 Liquid Lubricants, Classification and Properties

Liquid lubricants are classified into three category i.e.

(1) Natural or animal or Vegetable oil
(2) Mineral or Petroleum oil
(3) Synthetic or Blended oil.

Properties of different types of liquid lubricants are shown in table 4.5

Table 4.5 Liquid Lubricants: Classification and their Properties

Types of Liquid Lubricants	Examples	Composition and Properties
Natural or Animal or Vegetable Oil	• Animal oils, Tallow oil, Whale oil, Lard oil, Seal oil, Fish oil • Vegetable oils, Olive oil, Cotton seed oil, Castor oil, Palm oil, Rapeseed oils etc.	• Extracted from the crude fat and vegetables oils such as cotton seed oil and caster oils. These oils possess good oiliness & hence they can stick on metal surfaces effectively even under elevated temperatures and heavy loads. • Unstable in oxidative and thermal environment • Costly, undergo easy oxidation to give gummy products and hydrolyse easily on contact with moist air or water. Hence rarely used as blending agents in petroleum based lubricants to get improved oiliness.
Mineral or Petroleum Oil	• Paraffins, Napthenes, aromatic or mixed aromatic and aliphatic hydrocarbons. • Petroleum fractions	• Lower molecular weight hydrocarbons with about 12 to 50 carbon atoms. • Contains sulphur oxygen, phosphorous, nitrogen etc. • Generally lower viscosity index(VI) ($\approx$120 or less). • As they are cheap, available in abundance and stable under service conditions, hence are widely used. • Oiliness of mineral oils is less, so the addition of higher molecular weight compounds like oleic acid and stearic acid increases the oiliness of mineral oil. • Pour point is in the range of -6°C to -60°C. • Lower flash may provide sludge and varnish deposits.
Synthetic or Blended Oil	• Hydrocarbons produced by polymerisation, poly(alpha-olefins), organic esters, polyglycols, silicones.	• Desirable characteristics of lubricating oil can be improved by adding small quantity of various additives. The oils thus obtained are known as blended or compound oils. • The addition of higher molecular weight compounds like oleic acid, stearic acid, palmitic acid or vegetables oil like coconut oil, castor oil, etc increases the oiliness of mineral oil. • No impurities. • High viscosity index. • Pour point in the range of -18°C to -50°C. • Higher flash point to non-flammable. • Generally free of sludge and varnish deposits. They are of two types (i) Chemically active additives-e.g. detergents, antiwear agent, dispersant, oxidation inhibitors. (ii) Chemically inert additives-They improve the physical properties e.g. viscosity index improver, foam inhibitors, emulsifier, de- emulsifiers.

4.6.2 Semi-Solid Lubricants, Classification and their Properties

Semi-solid lubricants are obtained by combining lubricating oil with thickening agents such as grease. Lubricating oils may be petroleum oil or synthetic hydrocarbon of low to high viscosity. The thickeners may be special soaps of Li, Na, Ca, Ba, Al etc. Non soap thickeners include carbon black, silica gel, polyureas and other synthetic polymers, clays, etc. Grease can support much heavier load at lower speed. Internal resistance of grease is much higher than that of lubricating oils, therefore it is better to use oil instead of grease. Grease cannot effectively dissipate heat from the bearings, so work at relatively lower temperature. The most important semi-solid lubricants are greases and vaselines.

(A) Classification and Properties of Semi-Solid Lubricants

Classification and properties of semi solid lubricants are given in following table

Table 4.6 Classification and Properties of Semi Solid Lubricants

Types of Semi Solid Lubricants	Properties
Soda Based	Sodium soaps are used as a thickening agent in mineral or petroleum oil. They are slightly soluble in water. They can be used up to 175°C.
Lithium based	Lithium soaps are emulsifying with petroleum oil. They are water resistant and used up to 15°C.
Calcium based	Calcium soaps are emulsifying with petroleum oil. They are also water resistant and used up to 80°C. At higher temperature, soap and petroleum oil are separated from each other.

Lubricating greases are employed in the situations -

1. when a machine works at slow speeds and high pressures.
2. where spilling or spurting oil from the bearings is detrimental to the product being manufactured, for example in textile mills, paper and food product manufacture.
3. where oil cannot be maintained in position due to bad seal or intermittent operation
4. where the bearing has to be sealed against entry of dirt, water, dust and grit.

4.6.3 Solid Lubricants, Classifications and Properties

A solid lubricant is a material that separates two moving surfaces under boundary conditions and decrease the amount of wear. Graphite, molybdenum disulphide (MoS_2), boron nitride (BN)x are mostly used as a solid lubricant. They are used under high temperature and high pressure.

Graphite

It is most widely used as a solid lubricant. Graphite has layered structure [Fig. 4.1]. Layers are held together with the help of weak vander waals' forces which facilitate the easy sliding of one layer over the other layer. It is very soapy to touch, non-inflammable.It is used at higher temperature (around 450°C) condition.

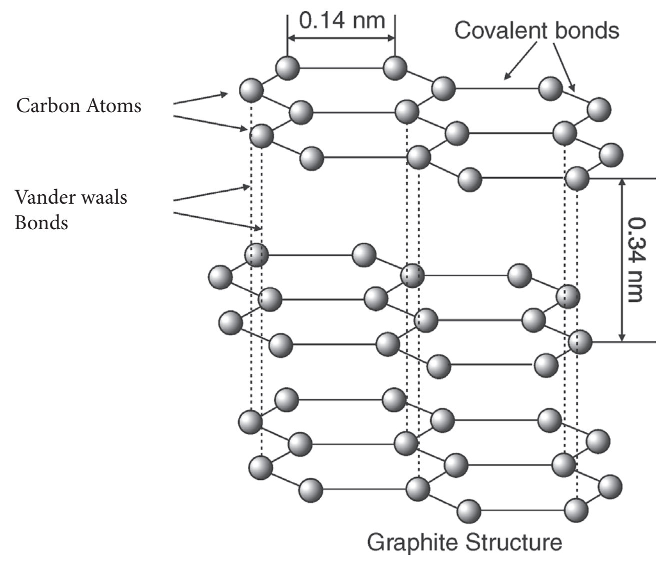


Fig. 4.1 Structure of Graphite

They are either used as powder form or mixed with oil or water.

Molybdenum disulphide (MoS_2)

It is sandwich like structure in which hexagonal layer of molybdenum (Mo) lies between two hexagonal layers of sulfur (S) atom. Like graphite each layers are held together with weak vanderwaals forces. It is stable up to 400^0C. It is used in high vacuum. It adheres even more strongly to the metal or other surface.

(A) Classification of Solid Lubricants

The various types of solid lubricants are as under :

(i) **Structural Lubricants:** Structural lubricants are those whose lubricating properties are due to their layer lattice structure. Example graphite, molybdenum disulphide, talc, mica, vermiculite etc. These function by cleaving within themselves and fixing themselves on or into bearing surface.

(ii) **Mechanical Lubricants:** They form a continuous adherent film on the rubbing surfaces and reduce the wear. Example Metals and plastics are characterised by their sacrificial wear.

(iii) **Soaps:** Soap function by in situ formation of compounds in the metal surface by the interaction of fatty acids and the metal.

(iv) **Chemically Active Lubricants:** These include extreme pressure additives and other chemicals which interact with the metal surface to produce a lubricating layer. Examples are phosphates, chlorides and oxidising agents.

(v) **Refractories, Ceramics and Glass:** These are used in defence programmes and rocketry. Combinations of refractory materials work satisfactorily as lubricants for short periods at high temperatures. Glass functions by softening at the operating temperature and assists in hydrodynamic lubrication.

Additives

The additive content in lubricating oils ranges from a few parts per million to several percentage depending on the function. They may be categorised as-

- Substances intended to improve the intrinsic characteristics of the base oils (viscosity index modifiers and pour point improvers).
- Lubricant protective substances (antioxidants).
- Substances giving new properties and protecting the metal surfaces of engines (detergents, dispersants, friction modifiers, anti-wear/extreme pressure (EP) additives, rust and corrosion inhibitors).

4.6.4 Emulsions

In machining operations such as milling, threading, turning and boring, the tools gets heated to a very high temperature, particularly at the cutting edge. In a cutting process, the pressure at the knife-edge may sometimes reach as high as 100,000 psi and a lot of heat is generated, which lead to oxidation and rusting of the metal. To prevent overheating and injury to the tool, efficient cooling and lubrication have to be provided. This is usually done by employing emulsions of oil droplets in water, which are called cutting oils or cutting fluids or cutting emulsions.

Oil has a poor specific heat but it has good lubricating properties, whereas water is a poor lubricant but it is an excellent cooling medium because of its high specific heat and high heat of vaporisation. Hence the combination of the two in the form of an emulsion can provide both lubrication and cooling effects. The corrosive action of water on the tools, the machines and the work piece are objectionable and is therefore checked by the addition of soaps or other inhibitive alkaline substances.

A good cutting oil increases the accuracy of the cuts and reduces the cost of the work by-

(a) making possible to achieve higher cutting speeds,
(b) prolonging the life of the cutting tool, and
(c) reducing the power demand and the number of rejects.

The two types of emulsions are used for lubricating jobs, as below

- **Oil-in-Water Type Emulsions or Cutting Emulsions.** These are prepared by mixing together an oil containing about 3 to 20% of a water soluble emulsifying agent (e.g., water soluble soap, alkyl or aryl sulfonate, alkyl sulphates) and suitable quantity of water. Chemicals like glycols, glycerols and triethanol amine are also added sometimes. Oil-in-water type emulsions are used as coolant cum lubricant for cutting tools and in diesel motor pistons and large internal combustion engines.
- **Water-in-Oil Type Emulsions or Cooling Liquids.** These are prepared by mixing together water and an oil containing 1 to 10% of water insoluble emulsifiers (e.g., alkaline earth metal soaps).

SAQ-2	Vegetable oils are placed under the category of		
	1. Natural Oil	2. Mineral Oil	3. Synthetic Oil

Key: 1

4.7 MECHANISM OF LUBRICATION

At microscopic or atomic level, all the surfaces in nature are rough. When two rough surfaces slide against each other, the rough surfaces come close to each other and interlock, adhere and generate friction. The purpose of lubrication is to separate the rubbing surfaces by a lubricant layer, which prevents or minimises direct contact of the bodies. By choosing appropriate lubricant, the friction and wear of the materials can be controlled.

The phenomenon of lubrication can be explained with the help of the following mechanism (a) Thick-Film lubrication or Fluid-Film or Hydrodynamic lubrication (b) Thin Film lubrication or Boundary lubrication.

4.7.1 Thick Film or Fluid Film or Hydrodynamic Lubrication

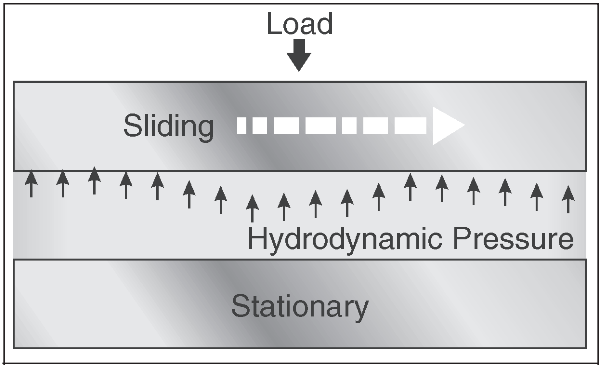


Fig.4.2 Thick Film Lubrication

Hydrodynamic is derived from the two words, hydro and dynamic. Hydro meaning liquid and dynamic meaning relative motion. In this mechanism, two moving and sliding surfaces are separated by thick film of lubricant fluid of about $1000A^0$, applied to prevent direct surface to surface contact and consequently reduce wear and tear of metals [Fig. 4.2]. The lubricant film covers/fills the irregularities of moving/sliding surfaces and forms a thick layer between them, so that there is no direct contact between the material surfaces. This consequently reduces the friction. The lubricant chosen should have the minimum viscosity (to reduce the internal resistance between the particles of the lubricant) and should remain in place and separate the surfaces. Hydrocarbon oils (mineral oils which are lower molecular weight hydrocarbons with about 12 to 50 carbon atoms) are considered to be satisfactory lubricants for thick-film lubrication. In order to maintain the viscosity of the oil in all seasons of year, ordinary hydrocarbon lubricants are blended with selected long chain polymers. In this case fluid is formed by mixing of hydrocarbon oils and anti-oxidants with long chain polymer so as to maintain viscosity. Fluid film lubrication is useful in delicate and light machines like watches, clocks, guns, scientific equipment.

4.7.2 Thin Film or Boundary Lubrication

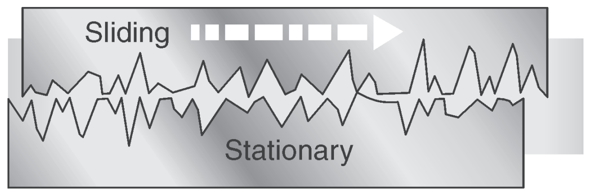


Fig 4.3 Boundary Film Lubrication

Boundary lubrication is a condition in which the lubricant film becomes too thin to provide total separation. Thin film lubrication is operating at relatively low speed and heavy loading or pressure [Fig. 4.3].

This type of lubrication is preferred where a continuous film of lubricant cannot persist when lubricant with lower viscosity is used. In such cases, the clearance space between the moving/sliding surfaces is lubricated by such a material which can get adsorbed on both the metallic surfaces by either physical or chemical forces or weak vander waals forces. This adsorbed film helps to keep the metal surfaces away from each other at least up to the height of the peaks present on the surface. Vegetable and animal oils and their soaps can be used in this type of lubrication because they can get either physically adsorbed or chemically react to the metal surface to form a thin film of metallic soap which can act as lubricant. Although these oils have good oiliness, but they will break down at high temperatures. On the other hand, mineral oils are thermally stable and by the addition of vegetable or animal oils to mineral oils, their oiliness can also be brought up. Graphite and molybdenum disulphide are also suitable for thin film lubrication.

4.8 PHYSICAL PROPERTIES OF LUBRICANTS

Some of the physical properties of lubricants are viscosity, viscosity index, oiliness, flash and fire point, cloud and pour point. We will learn these one by one.

4.8.1 Viscosity

Viscosity is the important physical property of a lubricant and is a measure of the intermolecular interactions of the oil and hence of the resistance to flow.

> Viscosity is the property of a fluid that determines its own resistance to flow. This resistance to flow of liquid is known as viscosity. Or scientifically a force in dynes required to move 1cm square of the liquid over another surface with a velocity of 1 cm per sec.

The unit of viscosity is poise. If the viscosity of the oil is too low, a liquid oil film cannot be maintained between two moving/sliding surfaces. On the other hand, if the viscosity of the oil is too high, excessive friction will result.

It is an indicator of flow ability of lubricating oil. The lower the viscosity, greater will be the flow ability. If temperature increases, viscosity of the lubricating oil decreases. If the pressure increases, viscosity of lubricating oil increases. Thus a good lubricating oil is that whose viscosity does not change with temperature [Fig.4.4].

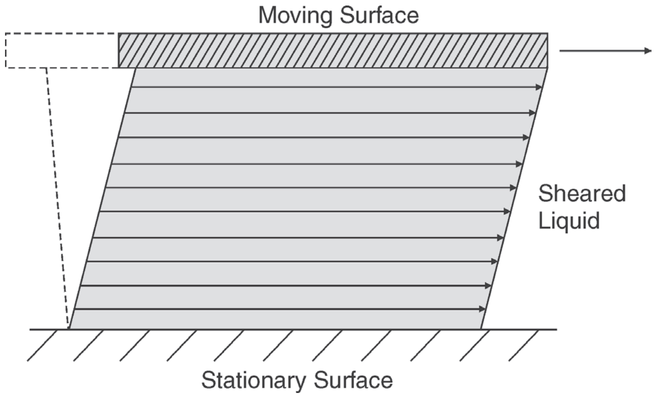


Fig. 4.4 Viscosity

Higher viscosity lubricants are thick and don't flow, while lower viscosity lubricants have a closer consistency to water and do flow. Example The ball sinks faster in the thinner, low viscosity oil while it sinks slower in the higher viscosity blends as oil heats up. We will be learning about the determination of viscosity of lubricating oil using Redwood viscometer in detail through practical performance in lab mentioned at the end of this unit.

4.8.2 Viscosity Index

> The variation of viscosity of a liquid with temperature is called viscosity index.

Viscosity of liquids decreases with increasing temperature and, consequently, the lubricating oil becomes thinner as the operating temperature increases. Hence, viscosity of good lubricating oil should not change much with change in temperature, so that it can be used continuously, under varying conditions of temperature.

The rate at which the viscosity of lubricating oil changes with temperature is measured by an arbitrary scale, known as viscosity index (V. I). If the viscosity of lubricating oil falls rapidly as the temperature is raised, it has a low viscosity index. On the other hand, if the viscosity of lubricating oil is only slightly affected on raising the temperature, its viscosity index is high.

Viscosity Index Improvers (VII) or Viscosity Modifiers (VM)

Viscosity Index Improvers, or Viscosity Modifiers influence the viscosity temperature trend. VIIs are polymers with a variable molecular weight belonging to the following main categories :

- Hydrogenated ethylene-propylene copolymers (also called Olefin Co-Polymers, (OCP)).
- Hydrogenated polyisoprenes which may be linear, partly branched or star-shaped.
- Polymetacrylates (PMA) of long-chain alcohols variable from C12 to C18, linear and/or partly branched.
- Hydrogenated styrene-isoprene copolymers, which may be linear, partly branched or star-shaped.
- Polyisobutenes (PIB). At a low temperature, these polymers have a closely-knit structure which minimizes interactions with the lubricant base; as temperature increases, the polymer increases its interactions with the base, extending its chains and expanding, countering the decrease in viscosity of the base. In the production of VMs, control of the molecular weight and its distribution represents a critical element as these parameters regulate two important characteristics of the polymer, i.e. its thickening power and its mechanical shear stability.

4.8.3 Oiliness

Oiliness of a lubricant is the measure of its capacity to stick on to the surface of machine parts under condition of pressure or load.

When a lubricating oil of poor oiliness is applied under high pressure, it gets squeezed out from the surface and lubrication stops. If the oil has good oiliness, it can remain in place and can give lubrication even under pressure.

It is an important property of a lubricant under boundary or thin film lubrication conditions. Mineral oils have very poor oiliness whereas animal and vegetable oils have good oiliness. Hence, oiliness of mineral oils is generally improved by adding small quantities of high molecular weight fatty acids like oleic acid, stearic acid, chlorinated esters of these acids, etc. There is no perfect method for the determination of absolute oiliness of on oil,only relative oiliness is considered while selecting a lubricating oil for a particular job.

4.8.4 Flash Point and Fire Point

Flash Point

The **flash point** of a volatile material is the lowest temperature at which vapours of the material will ignite for a moment when an ignition source brought near to it. The temperature at which a lubricant will ignite when heated and mixed with air, but a flame is not sustained.

The lubricating oil should have flash point reasonably above its working temperature

Fire point

The **fire point** of a fuel is the lowest temperature at which the vapour of that fuel will continue to burn for at least 5 seconds when an ignition source brought near to it.

In most cases, the fire points are 50°C to 40°C higher than the flash points. The flash and fire do not have any bearing with lubricating property of the oil, but these are important when oil is exposed to high temperature service. A good lubricant should have flash point at least above the temperature at which it is to be used. This safeguards against risk of fire, during the use of lubricant.

We will be learning about the determination of flash point and fire point of lubricating oil using Able's flash point apparatus in detail through practical performance in the lab mentioned at the end of this unit.

4.8.5 Cloud Point and Pour Point

Cloud Point : When the lubricant oil is cooled slowly, the temperature at which lubricating oil becomes cloudy in appearance is called **cloud point.**

Pour Point : The lowest temperature at which the lubricant oil become semi-solid and ceases to flow is called **pour point.**

Cloud and pour points indicate the suitability of lubricant oil in cold conditions or low temperature installations. Examples are refrigerators and air craft engines. Lubricant oil used in a machine, working at low temperatures should possess low pour point; otherwise solidification of lubricant oil will cause jamming of machine. It has been found that presence of waxes in the lubricant oil raise pour point. Pour point apparatus is used to determine cloud and pour point of lubricants.

SAQ-3	**Write True or False** **Good lubricants should have-**
	i) Lower flash and fire points than the operating temperature of the machine.
	ii) Lower cloud and pour point than the operating temperature of the machine

Key : i) False ii) True

4.9 CHEMICAL PROPERTIES OF LUBRICANTS

Some of the chemical properties of lubricants are coke number or carbon residue, total acid number (TAN) and saponification value.

4.9.1 Coke Number or Carbon Residue

Carbon residue of lubricant is an indication of the coke-forming tendency of an oil or in other words it is the tendency to form carbon deposits under high-temperature conditions in an inert atmosphere

It is considered to give an approximate indication of the combustibility of the fuel. Quantitatively it measures the carbonaceous residue remaining after the oil's evaporation and pyrolysis. The carbonaceous residue is correctly referred to as the carbon residue but is also often referred to as coke or thermal coke. For determination of carbon residue, Conradson's apparatus and Ramsbottom methods are used and may be expressed as a Ramsbottom carbon residue (RCR ASTM D524), a Conradson carbon residue (CCR-ASTM D189), or a micro carbon residue (MCR ASTM D5430). Numerically the CCR value is the same as that of MCR. Reporting units are percentage by mass (%m/m). Carbon residue is an indication of the fuel to decompose and form carbonaceous material that can plug diesel fuel injection nozzles.

The carbon residue value of fuel depends on the refinery processes employed in its manufacture. It ranges from 15-16% to 20% by mass. Carbon residue of oil affect the environment. The carbon is used by consumers in various forms and a large fraction is combusted into the atmosphere, thus creating massive amounts of the carbon dioxide, greenhouse gas as a waste product. Natural gas, mostly methane is even more potent greenhouse gas when it escapes into the atmosphere, prior to being burned. Residue (asphalt) hydrocarbons which are not boiled away remain after the distillation as hydrocarbons with more than 20 carbon atoms per molecule.

4.9.2 Total Acid Number (TAN)

Total Acid Number (TAN) is a measure of acid concentration present in a lubricant. The acid concentration of a lubricant depends on the presence of additives, acidic contamination, and oxidation by-products. The depletion of an additive package may cause an initial decrease in TAN of fresh oil.

TAN is a measurement of acidity that is determined by the amount of potassium hydroxide in milligrams that is needed to neutralise the acids in one gram of oil.

It is an important quality measurement of crude oil. TAN value itself can not be used to predict the corrosive nature of an oil, as the test only measures the amount of acid in a sample, not the specific quantities of different acidic compounds in the sample. Two sample might have same TAN value but one have high level of corrosive acids while the other may have low level of the same. Corrosive acids, an increase in viscosity and the formation of gums and refines are the negative effects attributed to increased TAN value. TAN values specify the quantity of acidic compounds present in the petrochemical sample. TAN is an analytical test to determine the deterioration of lubricants. The more acidic is the lubricant, the more degradation occurs. As fluid degrades, the level of corrosive acid increases along with danger of component failure.

It is usually the naphthenic acids in the crude oil that cause corrosion problems. This type of corrosion is referred to as naphthenic acid corrosion (NAC). TAN values may also be useful in other industries where oils are used as lubricants to determine oxidation and the subsequent corrosion risk to machinery. For example, compressor and turbine oils usually run at acid numbers of 0.01-0.25 mg KOH per gram of sample, gearbox and lube oil at 0.1-10 mg KOH per gram, and lubricant additives at 20-200 mg KOH per gram. Acidic characteristics are caused by numerous chemicals. For measurement of total acid number(TAN), potentiometric titration, colour indicating titration and spectroscopic methods are used.

Importance of TAN

- It is an important quality measurement of crude oil and used as a guide in the quality control of lubricating oil formulations. It is also sometimes used as a measure of lubricant degradation in service.
- Testing for TAN is essential to maintain and protect equipment, preventing damage in advance.
- TAN testing is a measure of both the weak organic acids and strong inorganic acids present within oil.

We will be learning about determination of TAN of given oil through practical performance in the lab, as mentioned at the end of this unit.

4.9.3 Saponification Value(SV) or Saponification Number (SN)

Saponification is the process by which the fatty acids in the triglycerides or fat are hydrolysed by an alkali to give glycerol and potassium salts of fatty acids. A known quantity of fat or oil is refluxed with an excess amount of alcoholic KOH.

Saponification Value or Saponification Number (SV or SN)

Saponification value of lubricating oil is the number of milligrams of potassium hydroxide (KOH) required to saponify one gram of fatty oil.

It is a measure of the average molecular weight (or chain length) of all the fatty acids present in the sample as triglycerides. Saponification number is an indication of the amount of fatty saponifiable material in a compounded oil. Caution must be used in interpreting test results if certain substances such as sulfur compounds or halogens are present in the oil, since these also react with KOH, thereby increasing the apparent saponification number.

Difference between Acid value and Saponification value

The key difference between acid value and saponification value is that acid value gives the mass of potassium hydroxide that is required to neutralise one gram of a chemical substance whereas saponification value gives the mass of potassium hydroxide required to saponify one gram of fat. Saponification literally means "soap making". The long chain fatty acids found in fats have low saponification value because they have a relatively fewer number of carboxylic functional groups per unit mass of the fat and therefore high molecular weight.

UNIT SUMMARY

- **Fuels :** Any combustible substance which on burning in air produces large amount of heat that can be used economically for domestic and industrial purposes.
- The calorific value of fuel is the amount of heat obtained by a complete combustion of unit mass of fuel.
- The octane number of gasoline is the percentage of iso-octane in the iso-octane and n-heptane mixture that matches the fuel being tested in a standard test engine.
- Any substance introduced between two moving/sliding surfaces with a view to reduce the friction or frictional resistance between them, is known as lubricants.

- **Lubrication :** The process of reducing friction between moving/sliding surfaces, by the introduction of lubricants in between them, is called lubrication
- Lubricants are classified as liquid, semi-solid,solid and emulsions
- Mechanisms of Lubrication can be understood by thick film or fluid film or hydrodynamic lubrication and thin film or boundary lubrication
- **Cloud & Pour Point :** When the lubricant oil is cooled slowly, the temperature at which lubricating oil becomes cloudy in appearance is called cloud point. The lowest temperature at which the lubricant oil become semi-solid and ceases to flow is called pour point. Good lubricant should have lower **Cloud and Pour Point than operating temperature of machine.**
- **Flash point and Fire Point :** The temperature at which a lubricant will ignite when heated and mixed with air is called as flash point. The fire point of a fuel is the lowest temperature at which the vapour of that fuel will continue to burn for at least 5 seconds when an ignition source brought near to it. Good lubricant should have higher flash point and fire point than operating temperature of machine.
- **Viscosity :** The resistance to flow of liquid is known as viscosity. Viscosity of liquids decreases with increasing temperature.
- **Oiliness :** Oiliness is the property of the lubricant by virtue of which a lubricating oil can stick on to the surface of the machine parts operating under high pressures.
- **Total Acid Number :** TAN is a measure of acid concentration present in a lubricant
- **Saponification number :** It represents the number of milligrams of potassium hydroxide (KOH) required to saponify one gram of fat.

EXERCISES

4.1 Define calorific values and mention its units.

4.2 Calculate high and low calorific value using Dulong's formula.

4.3 List and explain in brief the components involved in determination of proximate analysis of coal.

4.4 State octane number of gasolines. Mention the octane number of isopentane, n-hexane, benzene and cyclohexane.

4.5 Define cetane number. Give reasons for knocking of petrol engine.

4.6 Write the composition, calorific values and applications of LPG, CNG, biogas and coal gas.

4.7 List the characteristics of good lubricants.

4.8 Explain composition and properties of different types of liquid lubricants.

4.9 Explain the mechanism of lubrication using the concept of hydrodynamic lubrication.

4.10 State the following terms i) Viscosity and Viscosity index ii) Flash and Fire point iii) Cloud and Pour point.

4.11 Write the importance of coke number and TAN of lubricant.

4.12 Differentiate between acid value and saponification value.

PRACTICALS

1. ACID-BASE TITRATION

PRACTICAL STATEMENT

Determine total acid number (TAN) of given oil

PRACTICAL SIGNIFICANCE

Refer this unit 4 section 4.9.2

RELEVANT THEORY

Refer this unit 4 section 4.9.2

PRACTICAL OUTCOMES (PrOs)

PrO1 Weigh accurately the given sample in electronic balance
PrO2 Prepare sample solution .
PrO3 Perform titration for determining TAN

CHEMICALS AND GLASSWARE REQUIRED

- **Chemicals(AR Grade)** Oil sample, phenolphthalein indicator, KOH
- **Glasswares (Borosil)** Conical flask(100 ml), Burette(50 ml), pipette(10 ml), weighing balance (0.0001 mg sensitivity)

SAFETY PRECAUTIONS

1. Use apron, hand gloves while performing practical.
2. Handle the glasswares and chemicals carefully

SUGGESTED PROCEDURE

1. Weigh 1g of oil sample in conical flask.
2. Add 50ml of ethyl alcohol to oil to shake the solution to dissolve oil completely.
3. Add 2-3 drops of phenolphthalein indicator into the solution in conical flask.
4. Rinse and fill the burette with 0.01 N KOH solution
5. Titrate the solution in conical flask with 0.01 N KOH solution till colour changes from colourless to permanent light pink
6. Repeat the procedure for three consecutive burette readings.

OBSERVATIONS AND CALCULATIONS

1. Solution in burette ……………………......................
2. Solution in conical flask ……………….....……….
3. Indicator …………………..................................
4. End Point ………….........................……….

Observation Table

Readings	Pilot Reading	1	2	3	Mean Difference =(1+2+3)/3
Initial Burette Reading (IBR)					
Final Burette Reading (FBR)					
Difference (FBR-IBR)					

1000 ml of 1N KOH = 56.119 g of KOH

1 ml of 1N KOH = 5 6.119 mg of KOH

1 ml of 0.01 N KOH = 56.119 × 0.01 mg of KOH

(mean difference) ml of 0.01 N KOH = 56.119 × 0.01 × (mean difference ml) mg of KOH

Acid value of oil sample= 56.119×0.01×(mean difference mL) milligram of KOH /1g of Oil

= ....

Acid Value = __________.

RESULTS AND/OR INTERPRETATION

Acid Value of 1g of given sample of oil is ....

CONCLUSIONS AND/OR VALIDATION

…...

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. List available lubricant oil in market.
2. Give significance of acid value of an oil.
3. Relate the TAN with degradation of lubricant.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name………………………………..........………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Accuracy in weighing of sample	10		Viva-voce	10		
Preparation of solution and performing titration	30		Report preparation	10		
Housekeeping	10		Calculations,results and interpretation	10		
Handling of glasswares	10					
Observance/ follow Safety precautions	10					

2. MOISTURE AND ASH CONTENTS IN COAL

PRACTICAL STATEMENT

Estimate gravimetrically the moisture and ash contents in the given coal sample (Proximate Analysis).

PRACTICAL SIGNIFICANCE

Moisture, volatile matter, ash and fixed carbon are the main parameters to be determined for the estimating the quality of the solid fuel material such as coal coke. Moisture content is an important parameter in coal analysis. It is needed for determining the calorific (heating) value and handling properties of a coal. The ash yield provides information on how much material will be left after combustion, which will need to be disposed off. In the steel industry, low-ash contents are preferred for coking coals. Proximate analysis covers the determination of moisture, volatile matter, fixed carbon, and ash in coals and cokes, and is used to establish the rank of coals, to show the ratio of combustible to incombustible constituents, or to provide the basis for buying/selling, and otherwise evaluating coal for various purposes.

RELEVANT THEORY

Refer this unit 4, section 4.2.1

PRACTICAL OUTCOMES (PrOs)

PrO1 : Weigh the coal sample accurately.
PrO2 : Determine the moisture and ash contents in any given coal sample from any source.

RESOURCES REQUIRED

Electric balance, electric furnace, muffle furnace, pair of tongs, silica crucible, coal sample etc

SAFETY PRECAUTIONS

1. Handle oven and furnace very carefully under supervision.
2. Use pair of tongs while handling hot crucible.
3. Use hand gloves while using muffle furnance.

SUGGESTED PROCEDURE

Part A : Process of Determining the Moisture.

1. Weigh approximately 1 g of air dried coal sample in silica crucible.
2. Place the crucible in electric oven maintained at 105^0C for 1 hour
3. Find the difference between starting weight and the final weight of coal sample which represents the amount of moisture as the moisture is evaporated during heating.

Part B : Process of Determining the Ash.

1. Weigh exactly moisture free (from part A) coal sample in silica crucible.
2. Place the crucible in muffle furnace maintained at 750°C for 1 hour.
3. Find the weight of ash formed.

OBSERVATIONS AND CALCULATIONS

Part A: Determination of Moisture Content

1. Weight of empty crucible = W_1 =………….……g
2. Weight of crucible and coal sample before heating = W_2 =……………….g
3. Weight of coal taken =$W_3 = W_2 - W_1$ =………………g
4. Weight of silica crucible and coal sample after heating = W_4 =……………...g
5. Weight of moisture removed $W_5 = W_2 - W_4$ =………………g

$$\% \text{ of moisture content} = \frac{\text{Weight of moisture removed (W5)}}{\text{Weight of coal taken (W3)}} \times 100$$

$$= \frac{\text{……………………………}}{\text{……………………………..}} \times 100$$

Part B : Determination of Ash Content

1. Weight of empty crucible = W1 =……..……… g
2. Weight of silica crucible and coal sample before burning = W2 =……….g
3. Weight of coal taken =W3 = W2 - W1 =……………..g
4. Weight of silica crucible and ash = W4 =………..……..g
5. Weight of ash formed W5 = W4 - W1 =………………g

$$\% \text{ of ash content} = \frac{\text{Weight of ash formed (W5)}}{\text{Weight of coal taken (w3)}} \times 100$$

$$= \frac{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots} \times 100$$

RESULTS AND/OR INTERPRETATION

1. Percentage of moisture contents in coal =…………………………%
2. Percentage of ash contents in coal =…………………………%

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce

1. State the main function of proximate analysis of coal.
2. State the importance of determination of ash and moisture contents in coal.
3. Mention the different forms of coal.

DISPOSAL OF WASTE

Type of Waste	♻	**Details**
Biodegradable waste	Green bin	Burnt coal samples

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

While performing this experiment, use the desired amount of coal sample to reduce the waste.

SUGGESTED ASSESSMENT SCHEME

Name of the Student ………………………………………..…… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	% Weightage	Marks Obtained	Product Indicators (30%)	% Weightage	Marks Obtained	
Weighing of given samples	10		Viva-voce	10		
Process of moisture determination	20		Report preparation	10		
Process of ash determination	20		Calculation, results and interpretation	10		
Housekeeping	10					
Observance/ follow safety precautions	10					

3. CALORIFIC VALUE OF SOLID OR LIQUID FUEL

PRACTICAL STATEMENT

Determine the calorific value of solid or liquid fuel using bomb calorimeter

PRACTICAL SIGNIFICANCE

Bomb calorimeters are devices to compute the heat of combustion of a chemical reaction. Such information helps the scientists to know better, whether certain food products are safe for use or not. A bomb calorimeter can be used to determine higher gross calorific value (GCV) of solid and liquid fuel. Higher GCV means lower specific fuel consumption. Amount of air required for combustion can be pre calculated. Specific fuel consumption can be reduced substantially using good quality fuel.

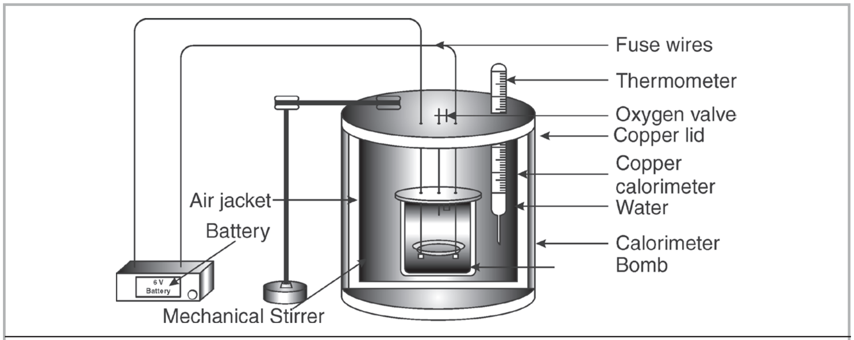
RELEVANT THEORY

The calorific value is the most important property of fuel. It may be defined as the total quantity of heat liberated by the complete combustion of a unit mass of the fuel. The calorific value determines the quality of fuel and also helps in calculating thermal efficiency and heat balance in the process where coal is used as a fuel. The Higher Calorific Value (HCV) or Gross Calorific Value (GCV) is obtained when water formed by combustion is completely condensed. The Lower Calorific Value (LCV) or Net Calorific Value (NCV) is obtained when the water formed by combustion exists completely in the vapour phase. [Refer this unit 4 section 4.1 to 4.1.4] Basically, this device burns a fuel sample and transfers the heat into a known mass of water. Basically, bomb calorimeter burns a fuel sample and transfers the heat into a known mass of water.

PRACTICAL OUTCOMES (PrOs)

PrO1 Weigh accurately the given sample in electronic balance.
PrO2 Prepare standard solution of given sample of defined molarity and normality.
PrO3 Use the bomb calorimeter to determine the calorific value of any other solid or liquid fuels.

10.5 PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)



Bomb calorimeter

The bomb calorimeter consists of a strong steel shell known as a bomb. It consists of a base which supports the platinum crucible and is screwed to the body of the bomb. The top of the bomb carries an oxygen supply connection and a valve to release the product. The electrodes extend through the base of the bomb and connect the fuse wire to an electric circuit. The coal can be ignited by closing the electric circuit. The bomb is placed inside a copper vessel which contains water. There is a stirring device for agitating the water within the calorimeter. The calorimeter containing the bomb is placed in another container which acts as a heat insulator. The temperature of water in the calorimeter is measured by a thermometer.

RESOURCES, CHEMICALS, GLASSWARE REQUIRED

Resources Electronic balance (0.0001mg sensitivity), electric oven (size-18” × 18” × 18”) 40 litre capacity temperature up to 250^{0}C, standard bomb calorimeter, silica crucible, pair of tongs, coal sample

SAFETY PRECAUTIONS

1. Handle the calorimeter under the supervision of teacher.
2. Use pair of tongs while handling crucibles.
3. Never approach the calorimeter from top due to danger of explosion.

SUGGESTED PROCEDURE

1. Take about 1 g of solid fuel sample in a silica crucible introduce it into the bomb calorimeter
2. Add the 2000 mL of distilled water, start the stirrer and note down the initial temperature of water.
3. Pass the oxygen gas at about 20 to 25 atm.
4. Start current through the crucible and let the fuel sample to burn in presence of oxygen.
5. The fuel is burnt by producing electric spark inside the bomb calorimeter.
6. Heat released during combustion of sample fuel is taken by water, due to which temperature of water increases.
7. Record the final constant temperature.
8. Water equivalent of calorimeter is determined by repeating the same procedure using benzoic acid which is the standard fuel of known GCV.

OBSERVATIONS AND CALCULATIONS

Sr. No	Description	Weight in grams
1	Water equivalent of bomb calorimeter = fixed for calorimeter or can be calculated by burning benzoic acid=(m1)	
2	Mass of water in copper calorimeter (m2)	
3	Specific heat of water (Cw)	
4	Weight of solid fuel coal sample taken Ws	
5	Initial temperature of water (t1)	
6	Final temperature of water (t2)	

Calculations

Heat liberated by Ws kg of fuel in vessel = Heat absorbed by (m1+m2) kg of water in bomb ……(1)

We know that heat liberated by 1kg of fuel in closed apparatus = GCV

Heat liberated by Ws kg of fuel in closed apparatus = GCV × Ws……………… ……(2)

Heat absorbed by 1kg of water to raise its temperature by 10^0C = specific heat of water =4.187 kJ/ kg/^{0}C

Heat absorbed by (m1 + m2) kg of water to raise its temperature

From t1 to t20C=(m1+m2) × (t2 – t1) ×Cw……………………………………… ……(3)

Substituting equation 2 and 3 in equation 1

GCV × Ws =(m1+m2) × (t2 – t1) × Cw

$$\text{Gross Calorific Value (GCV)} = \frac{(m1+m2) \times (t2-t1) \times Cw)}{Ws}$$

$$= \frac{(\ldots\ldots\ldots) \times (\ldots\ldots\ldots) \times (\ldots\ldots\ldots)}{(\ldots\ldots\ldots)}$$

Calorific value = …………………….Cal/g

Calorific value = …………………….× 4.183 ×10^3 J/kg = ……………J/Kg

RESULTS AND/OR INTERPRETATION

Calorific value of sample fuel is ……………………

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Name the fuel which has highest calorific value.

2. Explain the significance of calorific value.
3. Explain the purpose of bomb in bomb calorimeter.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name………………………………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Accuracy in weighing of sample	10		Viva-voce	10		
Preparation of solution	10		Report preparation	10		
Housekeeping	10		Calculations, results and interpretation	10		
Performance using bombs calorimeter	20					
Observance/ follow safety precautions	20					

4. VISCOSITY OF LUBRICATING OIL

PRACTICAL STATEMENT

Determine the viscosity of lubricating oil using Redwood viscometer

PRACTICAL SIGNIFICANCE

Viscosity or the thickness of the oil is important because it determines the lubricant's film strength and efficiency in preventing friction between moving parts. If a lubricant is too thin, the film may not be thick enough to prevent friction.

Use of the correct viscosity lubricant for the speed, temperature and loads ensures the development of a full oil film between rotating parts. The optimum fluid film is sufficiently thick to allow the rolling elements to function without metal-to-metal contact with minimum friction.

RELEVANT THEORY

Refer this unit 4, section 4.8.1 and 4.8.2

PRACTICAL OUTCOMES (PrOs)

PrO1 Use Redwood viscometer to determine the viscosity of different types of lubricating oil.

PrO2 Find the relation between viscosity and temperature from graph.

PrO3 Select the relevant lubricant for applying in different applications.

PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)

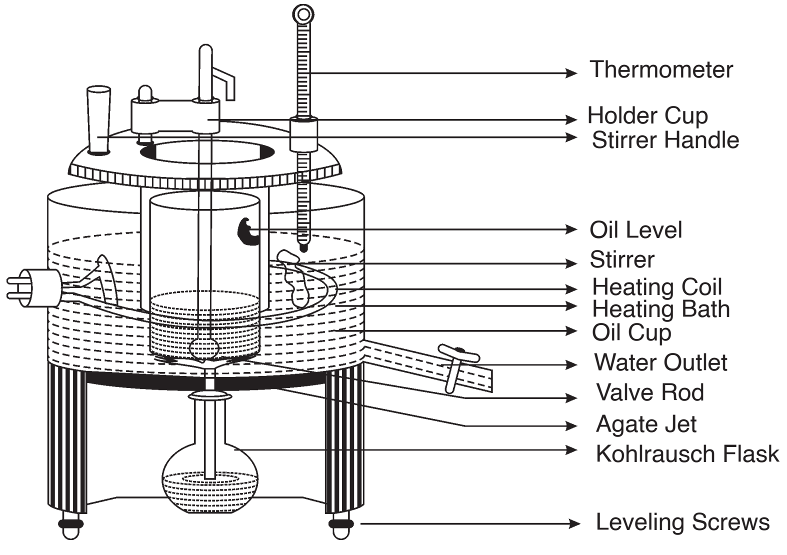


Fig. Redwood Viscometer

Viscosity of lubricating oil is measured with the help of viscometer. In a viscometer fixed volume of the liquid is allowed to flow from a given height, through a standard capillary tube under its own weight and the time, of flow in seconds is noted. The time in seconds is proportional to true viscosity. Redwood viscometer is used to measure viscosity of lubricant oil. It is of two types. Redwood viscometer No 1 is used to measure viscosity of low viscous lubricant oil. It has jet of bore diameter 1.62 mm and length 10 mm. Redwood viscometer No 2 is used to measure viscosity of highly viscous lubricant oil. It has a jet of diameter 3.8 mm and length 15 mm

RESOURCES, CHEMICALS AND GLASSWARES REQUIRED

- **Resources** Redwood viscometer No1(standard), stop watch, Lubricating oil (60 mL), Thermometers.
- **Glasswares** (Borosil) Kohlrausch flask (50 mL- flask with marking upto 50mL), measuring cylinder [100 mL]),

SAFETY PRECAUTIONS

1. Determine the viscosity at higher temperature first and then to lower temperature.
2. Level the instruments with the help of leveling screws on the tripod of Redwood viscometer.
3. Use stirrer during heating for maintaining uniform desired temperature.

SUGGESTED PROCEDURE

1. Fill the water in water bath, to the height corresponding to the tip of indicator up to which the oil is filled in the cylindrical cup.
2. Keep the brass ball of valve rod in position so as to seal the orifice.
3. Pour the oil under test carefully into the oil cup upto the tip of the indicator.
4. Weigh empty Kohlrausch flask or empty measuring cylinder as W1.
5. Keep an empty 50mL Kohlrausch flask (or measuring cylinder) in position below the jet.
6. Place the thermometers, one in oil and other in water.
7. Keep the oil and water well stirred and note their temperatures.
8. When the temperature of oil and water are steady at 60°C, raise the ball valve and suspend it from the thermometer bucket and simultaneously start the stop watch.
9. When level of oil dropping into the Kohlrausch flask reaches to the 50mL mark, stop the stop watch and note the time in seconds, called as time of efflux.
10. Weigh the flask with 50mL oil record as W2
11. Replace the ball value in position to seal the cup to prevent overflow the oil.
12. Refill the oil up to the indicator tip of the oil cup.
13. Record the time required to efflux the oil for different temperatures say 50°C and 40°C.
14. Record the time of efflux as explained above.
15. Plot graph between viscosity (y-axis) vs temperature (x-axis).

OBSERVATIONS

Weight of empty kohlrausch flask =W1 g =…...............…g

Weight of flask + 50mL oil =W2 g =…………………g

Weight of oil =W= W2-W1 =…...............…g

Density of oil $==\frac{\text{Weight of oil}}{\text{Volume of oil}}=\frac{w}{50}=$……….g/m^3=…………×1000 =…………Kg/m^3

3 Specific gravity of oil 'S'$=\frac{\text{Density of oil}}{\text{Density of water}}=\frac{\rho}{1}=\frac{\cdots\cdots}{1}=$

Sr. No.	Temp°C	Time for Collecting of 50mL Oil (R) (Sec)	Weight of Oil W (g)	Density of Oil (Kg/m^3)	Specific Gravity of oil (s)	Redwood Number RN (Sec)	Kinematic Viscosity (ν = in m^2/s)	Absolute Viscosity ($\eta = \nu \times \rho$ in Ns/m^2)
1	60							
2	50							
3	40							

Redwood Number (RN) $=\frac{K\,R\,S}{R1S1}=\frac{\cdots\cdots\cdots}{\cdots\cdots\cdots}=\frac{\cdots\cdots\cdots}{\cdots\cdots\cdots}$

Where

K is constant =100, R= time for collecting 50mL of oil,

S- specific gravity of oil, R1 is constant =535,

s1 is specific gravity constant of oil = 0.915

If RN is below 100, use formula as follows

Kinematic viscosity $V=\left[0.26\times RN-\frac{179}{RN}\right]\times10^{-6}$ m^2/s

If RN formula is above 100 then use formula as $\eta = V\times\rho$ in

Kinematic viscosity $V=\left[0.247\times RN-\frac{50}{RN}\right]\times10^{-6}$ m^2/s

Dynamitic viscosity or Absolute viscosity

RESULTS AND/OR INTERPRETATION

1. Viscosity of given lubricating oil at room temperature………………………………
2. From graph as temperature increases viscosity of given oil……………………..

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Explain the viscosity of engine oil.
2. Mention the effect of temperature and pressure on viscosity of lubricating oil.
3. Mention the relation between viscosity and thickness.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin) ♻	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.

2. While performing this experiment, use the desired amount of substance to reduce the waste.

3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name………………………….....…………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Measurement of viscosity	30		Viva-voce	10		
Housekeeping	10		Report preparation	10		
Use redwood viscometer	20		Calculation, results and Interpretation	10		
Observance/ follow safety precautions	10					

5. FLASH POINT AND FIRE POINT OF LUBRICATING OIL

PRACTICAL STATEMENT

Determine the flash and fire point of lubricating oil using Abel's flash point apparatus

PRACTICAL SIGNIFICANCE

The flash and fire points are useful in determining lubricant's volatility and fire resistance. The flash point can be used to determine the transportation and storage temperature requirements for lubricants. The flash point is applicable in fire investigation and fire protection because it is the lowest temperature at which a risk of fire exists within a given liquid. Lubricant's producers can also use the flash point to detect potential product contamination. Products with a flash point less than 38^0C (100^0F) will usually require special precautions for safe handling. The fire point for a lubricant is usually 8 to 10 percent above the flash point. The flash point and fire point should not be confused with the auto-ignition temperature of a lubricant, which is the temperature at which a lubricant will ignite spontaneously without an external ignition source.

RELEVANT THEORY

Flash point is the lowest temperature at which a liquid can gives off vapour to form an ignitable mixture in air near the surface of the liquid or ignition of a substance initiates. The fire point describes the lowest temperature at which the fuel continues to burn for a short time period after the initiation of the ignition. The fire point is usually a few degrees above the flash point.

PRACTICAL OUTCOMES (PrOs)

PrO1 Find flash and fire point of lubricating oil

PrO2 Use the Abel's flash point apparatus for determining the flash and fire point of any lubricating oil.

PrO3 Select the suitable lubricating oil

12.5 PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)

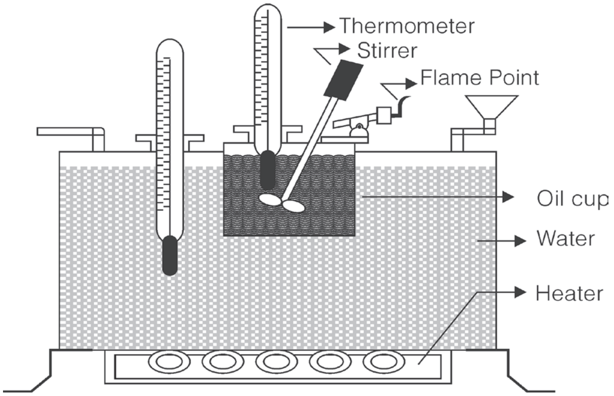


Fig. Abel's Apparatus

Abel's apparatus consists of cylinder brass cup surrounded by a double jacketed copper water bath which is enclosed in a copper casing mounted on an iron tripod. The oil cup is provided with a brass cover having arrangement for small test flame, a sliding shutter covering three small opening in the lid and opening for a paddle stirrer and the standard thermometer, the bulb of which should be immersed in the oil.

RESOURCES

Abel's standard apparatus, spirit lamp, water bath, lubricating oil

SAFETY PRECAUTIONS

1. Stir oil continuously by turning the paddle stirrer. Stirring should be discontinued only during the introduction of test flame over the oil surface.
2. Adjust the heating in such way that the temperature of the oil increases at the rate of 1 to 1.5°C per minute.
3. Use pair of tongs to remove oil cup from the apparatus.
4. Care and need to be taken while introducing test flame over the oil surface

SUGGESTED PROCEDURE

1. Fill the cup with oil under the test upto the point of gauge and place the cover.
2. Fix the oil cup into the apparatus and assemble the paddle stirrer and standard thermometer with its bulb dipping into oil at their respective places provided in the apparatus.
3. Fill the water bath with cold water.
4. Close the sliding shutter and light the standard flame.
5. Switch on the heating arrangement.
6. At every degree rise of oil temperature, upon the sliding shutter. Introduce the flame over the oil surface through the central opening to see whether the oil gives flash and fire . Record the minimum temperature at which a distinct flash appears as the flash point of oil.
7. Increase the temperature again gradually up to fire point so that lubricant vapors can burn continuously more than 5 sec.
8. After getting the fire point remove the oil cup from apparatus for cooling.
9. During cooling verify the observed readings.

RESULTS AND/OR INTERPRETATION

1. Selected Lubricant oil gives flash point at ………°C
2. Selected Lubricant oil gives fire point at ……….°C

CONCLUSIONS AND/OR VALIDATION

…………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. State the significance of flash point.
2. Explain the difference between flash point and fire point.
3. Relate boiling point with flash point.
4. At what temperature will petrol ignite
5. Which is more flammable, petrol or kerosene

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name………………………………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	% Weightage	Marks Obtained	Product Indicators (30%)	% Weightage	Marks Obtained	
Fixing the cup with lubricant and thermometer	20		Viva-voce	10		
Finding flash point	10		Report preparation	10		
Finding fire point	10		Results and Interpretation	10		
Housekeeping	10					
Adjustment of heating	10					
Observance/ follow safety precautions	10					

KNOW MORE

- Determination of flash point and fire point and cloud and pour point by different standard methods through practical performances.
- Knowledge about aniline point.
- Soft soap are the potassium salts of higher fatty acids.
- Hard soaps are sodium salts of higher fatty acids.
- Detergents are generally ammonium or sulphonate salts of long chain carboxylic acids. They are also called as soapless soap

Suggested Micro projects / activities

- Collect different oil samples and prepare soap using different alkalis and record amount of alkali required to prepare soap, type of soap formed.
- Collect samples of petrol, kerosene oil, diesel, any edible oil,coconut oil. Find out the flash point and fire point,cloud and pour point and viscosity of the same. Compare the properties and justify their use in relevant applications.
- Depending on the type of machinery, load applied, speed of machine, heat generated, etc, select the appropriate lubricant which can be applied into the machinery. Discuss with your teachers and colleagues and present the same.

Inquisitiveness and Curiosity

- By using potassium salt we can prepare soft soap while from sodium salt we can prepare hard soap.
- Our country is known for rich agricultural produce such as soyabean, mustard etc. We are able to extract edible oil out of these crops. Can our scientists explore the innovative methods to convert/ modify these oils with wide range of properties to cater to the requirement of spectrum of industries and machineries for lubrication purpose.

REFERENCES AND SUGGESTED READINGS

- C. N. R. Rao, Understanding Chemistry, Universities Press (India) Pvt. Ltd., 2011, ISBN 8173712506.
- Dara, S. S. & Dr. S. S. Umare, Engineering Chemistry, Universities Press (India) Pvt.Ltd., 2011, ISBN, 8121903599.
- Jain & Jain, Engineering Chemistry, Dhanpat Rai and Sons; New Delhi, 2015, ISBN 8187433175.
- Shikha Agarwal, Engineering Chemistry, Cambridge University Press; New Delhi, 2015. ISBN, 978-1-107-47641-7.

5

Electrochemistry

UNIT SPECIFICS

This unit comprises of the following major topics:

- Electronic Concept of Oxidation and Reduction
- Electrolytes and Non Electrolytes
- Industrial Applications of Electrolysis
- Application of Redox Reactions in Electrochemical Cells
- Corrosion
- Factors Influencing Rate of Corrosion
- Internal Corrosion Preventive Measures

The different concepts have been explained through examples for generating further curiosity and inquisitiveness and also developing creative problem solving abilities in the students,with the mention of their practical applications in the industries/day to day life.

Assessment for learning at different intervals within the unit, at different levels of cognitive domain is carried out by designing formative assessment questions.

For effective implementation of the outcome based curriculum in true spirit, wide spectrum of activities such as micro projects, assignments, industrial visits etc, are designed and integrated in the unit for the benefit and exposure of the students. Sample QR codes have been provided on various topics/sub topics for supplementary reading and reinforcing the learning.

RATIONALE

Electrochemistry is the branch of physical chemistry that deals with the interdependence of chemical changes and electrical energy. Electrochemistry deals with broad applications like metal extraction, metal protection, metal recovery, and electrical energy generation from chemical energy and the sun. Electrochemistry is essential for safe, effective and efficient operations, from metal protection to semiconductors to advanced batteries. Corrosion can be viewed as a universal phenomenon, omnipresent and omnipotent. Losses due to corrosion could be around Rs. 2.0 lakh crores per annum in India. Corrosion has a huge economic and environmental impact on all facets of national infrastructure, from highways, bridges, buildings, oil and gas, chemical processing, water and waste water treatment and on all metallic objects in use. Corrosion also interferes with human safety,disrupts industrial operations and poses danger to environment. Awareness to corrosion and adaptation of timely and appropriate control measures are the key in the abatement of corrosion failures.

PRE-REQUISITES

Chemistry : Solution, engineering materials

Mathematics : Basic algebra and geometry

UNIT OUTCOMES

List of outcomes of this unit are as follows :

U5- O1 Identify oxidation – reduction process on the basis of loss and gain of electron.

U5- O2 Apply Faraday's laws of electrolysis to determine weight of substance deposited or liberated.

U5- O3 Use the different types of cells based on their mechanism and characteristics.

U5- O4 Use the different electrolysis process such as electrometallurgy, electroplating and electro-refining to solve the wide variety of problems of industries.

U5- O5 Select the relevant method to prevent the metals from corrosion.

Unit - 5 Outcomes	Expected Mapping of Unit Outcomes with the Course Outcomes (1- Weak Correlation; 2- Medium Correlation; 3- Strong Correlation)				
	CO-1	CO-2	CO-3	CO-4	CO-5
U5-O1	1	-	-	-	3
U5-O2	-	-	-	-	3
U5-O3	-	-	-	-	3
U5-O4		-	1	-	3
U5-O5	-	-	1	1	3

5.1 ELECTROCHEMISTRY AN INTRODUCTION

Electrochemistry is the branch of chemistry that deals with the inter conversion of electrical energy into chemical energy. Electric current flows from higher electric potential to lower electric potential. Electric current is the flow of electrons through a wire or solution. In solid state, the electrons are passed from one positively charged metallic atom to the next atom, while in a solution or a fused state, the electrons are carried by the ions present in the solution. Hence free electrons in metals are responsible for the conduction of electricity, while ions are responsible for the conduction of electricity in a fused state or solution.

Interesting Fact

Allen J. Bard is the pioneer in electrochemistry for over 60 years and considered as father of Modern Electrochemistry.

5.1.1 Electronic Concept of Oxidation-Reduction

We come across many processes like burning of fuels, rusting of metals, extraction of metal, and protection of metal, electroplating etc. All are based upon the redox reactions. These redox reactions are the basis of electrochemistry. Let us understand certain terms oxidation, reduction and redox reactions.

Oxidation : It is the process that involves the loss of electrons by an atom, ion or molecule.

The loss of electrons involves an increase in positive charge or decrease in negative charge of species undergoing oxidation.

$2Na \longrightarrow 2Na^+ + 2e^-$ (1)

2,8,1 2,8

Sodium loses one electron, oxidation reaction takes place at sodium.

$Cu \longrightarrow Cu^{2+} + 2e^-$ (2)

In the case of copper metal, it loses two electrons, oxidation reaction takes place at copper.

$Pb^{2+} \longrightarrow Pb^{4+} + 2e^-$ (3)

(II) (IV)

Reduction It is the process that involves the gain of an electron by atom ion or molecule.

The gain of electrons results in the decrease of positive charge or increase of negative charge of the species.

$Cl_2 + 2e^- \longrightarrow 2Cl^-$ (4)

Chlorine Chloride

$O + 2e^- \longrightarrow O^{2-}$ (5)

Oxygen Oxygen ion

$Pb^{4+} + 2e^- \longrightarrow Pb^{2+}$ (6)

(IV) (II)

Redox or Net Reactions : These are interdependent reactions in which one species is reduced and other is oxidized.

Consider the formation of sodium chloride. Reaction no (1) and (4) is called half cell reaction, showing the involvement of electrons. The Sum of the half-reactions gives the overall reactions called Redox or Net reaction.

$2Na \longrightarrow 2Na^+ + 2e^-$ Oxidation

$Cl_2 + 2e^- \longrightarrow 2Cl^-$ Reduction

$2Na + Cl_2 \longrightarrow 2Na^+ + 2Cl^- \longrightarrow 2NaCl$ Redox/ Net Reaction

In the reaction between sodium and chlorine to yield sodium chloride, sodium is oxidized (its oxidation number increases from 0 in Na to +1 in NaCl) and chlorine is reduced (its oxidation number decreases from 0 in Cl_2 to - 1 in NaCl).

SAQ1	Following reaction is an example of $Pb^{2+} \longrightarrow Pb^{4+} + 2e^-$		
	1. Oxidation Reaction	2. Reduction Reaction	3. Redox Reaction

Key: 1

5.2 ELECTROLYTES AND NON ELECTROLYTES

A solid substance that allows electric current to pass through it is called a conductor e.g. all metals, graphite. When a substance is present in solution, the conduction of electricity can be expressed in the following way.

5.2.1 Electrolytes

Electrolyte : Substance in fused state or in solution generates ions and allow electricity to pass through is known as electrolyte or electrolytic conductor

Example Fused NaCl, NaCl solution, $CuSO_4$ solution, HCl, H_2SO_4,KOH, NaOH, NH_4OH, CH_3COOH. NaCl salt in a fused state gives two ions, positively charged Na^+ cation and negatively charged Cl^- anion. When electricity is passed through a fused state,cations and anions present in the solution are responsible for the conduction of electricity. Hence fused NaCl is an electrolyte.

Electrolytes are of two types

(A) Strong Electrolyte B) Weak Electrolyte

(A) Strong Electrolyte Solutes are strongly or highly dissociated or ionised into cation and anion, when dissolved in a solvent.Solutes like HCl, H_2SO_4, KOH, NaOH, and NaCl are highly separated into cations and anions, called strong electrolytes or strong solutes.

- **(i) Dissociation** Separation of already existing ions is called dissociation. e.g. When ionic compounds like NaCl dissolve in the solvent, it gets separated into Na^+ and Cl^- and the process is called dissociation.
- **(ii) Ionisation** Generation and separation of ions called ionisation. e.g. When a covalent compound like HCl dissolves in solvent, generates ions H^+ and Cl^- and the process is called ionisation.

(B) Weak Electrolyte Solutes are weakly or feebly ionised into cations and anions, when dissolved into a solvent. Solutes like NH_4OH, CH_3COOH are weakly dissociated hence called weak electrolytes

Fraction of total number of solute molecules that are dissociated or ionised known as degree of dissociation as shown in table 5.1 (Values are only for concept clarity).

Table 5.1 Strong Electrolyte and Weak Electrolyte

Solute	Cation	Anion Dissociation	Degree of Electrolyte	Strong or Weak
HCl	H^+	Cl^-	90/100	Strong Electrolyte
H_2SO_4	$2H^+$	$SO4^{2-}$	95/100	
HNO_3	H^+	NO_3^-	92/100	
KOH	K^+	OH^-	88/100	
NaOH	Na^+	OH^-	92/100	
NaCl	Na^+	Cl^-	100/100	
CH_3COOH	H^+	CH_3COO^-	40/100	Weak Electrolyte
NH_4OH	NH_4^+	OH^-	45/100	

5.2.2 Non Electrolyte

Substance in fused state or in solution does not generates ions and does not allow electricity to pass through it is known as non-electrolyte.

When electricity is passed through non-polar solutions like benzene or CCl_4 or CS_2 or sugar solution, methane, ethane, there is an absence of ions, hence these solutions are examples of non-electrolytes.

5.2.3 Faraday's Law of Electrolysis

(A) Faraday's First law of Electrolysis

> The weight of substance deposited or liberated at an electrode is directly proportional to the quantity of electricity passed through the electrolytes.

Mathematically,

$$W \propto Q$$

$$W \propto It \quad \therefore Q = I\,t$$

$$W = ZIt$$

Where W - Weight of substance deposited or liberated at an electrode(in grams)

Q - Quantity of electricity passed through electrolyte (in coulombs) Proportionality constant is electrochemical equivalent (E.C.E.)and represented by 'Z' (in g/coulomb)

I - Current in ampere

t - Time in seconds

When t=1 sec, and I= 1 ampere then W= Z x 1 x 1

$$\boxed{W = Z}$$

> When one ampere of current is passed through one second, then weight of substance deposited or liberated is equal to **electrochemical equivalent** (Z)

We will be learning in depth about the determination of electrochemical equivalent of copper metal using Faraday's first law of electrolysis through practical performance mentioned in lab manual annexed at the end of this unit.

(B) Faraday's Second Law of Electrolysis

When the same quantity (amount) of electricity is passed through different electrolytes arranged in series, then the weights of the different substances deposited or liberated at the respective electrodes are directly proportional to their chemical equivalent (equivalent weights of the substances).

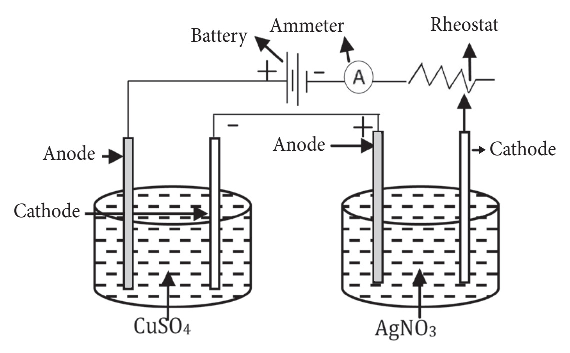


Fig. 5.1 Faraday's Second Law of Electrolysis

Let the same amount of electricity is passed through two cells connected in series and containing the solution of say copper sulphate & silver nitrate respectively, [Fig. 5.1], then according to Faraday's second law of electrolysis, weight of silver and copper deposited will be proportional to their equivalent weight also known as chemical equivalent.

$$\text{Weight of copper deposited}(W_1) \propto \text{Equivalent weight of copper }(E_1) \quad (1)$$

$$\text{Weight of silver deposited}(W_2) \propto \text{Equivalent weight of silver}(E_2) \quad (2)$$

Dividing equation 1 by 2 we get,

$$\frac{\text{Weight of copper deposited }(W_1)}{\text{Weight of silver deposited }(W_2)} = \frac{\text{Equivalent weight of copper}(E_1)}{\text{Equivalent weight of silver }(E_2)}$$

Thus, by knowing the three terms, we can calculate the fourth very easily.

$$\frac{W1}{W2} = \frac{E1}{E2}$$

SAQ 2	According to Faraday's first law of electrolysis, weight of substance deposited is			
	1.directly proportional to chemical equivalent	2. inversely proportional to equivalent weight	3.inversely proportional to electro-chemical equivalent	4. directly proportional to electro chemical equivalent

Key: 4

Relation between Faraday and Coulomb

From Faraday's second law,the quantity of electricity which liberates one gram equivalent of copper is 31.75 g of copper, or one gram equivalent of silver, i.e.107.88g of silver.

Electrochemical equivalent of silver i.e. 0.001118 g. will be deposited by 1 coulomb of electricity

For deposition of 0.001118 g of silver it requires 1 Coulomb of electricity

hence for the deposition of 107.88 g silver, the quantity of electricity would be

$$\text{For silver} = \frac{107.88}{0.001118} = 96496 \text{ coulombs}$$

Electrochemical equivalent of copper i.e. 0.000329 g. will be deposited by 1 coulomb of electricity

For deposition of 0.000329 g of copper it requires 1 Coulomb of electricity

Hence to liberate 31.75 g equivalent of copper, the quantity of electricity would be

$$\text{For copper} = \frac{31.75}{0.000329} = 96504 \text{ coulombs}$$

Faraday experimentally determined that the average quantity of electricity required to liberate or deposit one gram equivalent of any substance from its solution hence this quantity is known as one Faraday (F).

1 Faraday = 96500 coulombs

Relation between Equivalent Weight (C.E.) and Electrochemical Equivalent (E.C.E)

96500 coulomb ≡ 1 gram equivalent of substance or Chemical equivalent of substance

1 Coulomb ≡ 1 gram electrochemical equivalent of substance (E.C.E. of substance)

∴ 1 g chemical equivalent of substance =96500 x electrochemical equivalent of substance

C. E . = 96500 x E. C. E.

Thus the equivalent weight of the substance is 96500 times the electrochemical equivalent

5.3 INDUSTRIAL APPLICATIONS OF ELECTROLYSIS

In the electrolysis process,by using electrical energy,chemical changes are taking place. Hence in these cells, non-spontaneous chemical reactions are taking place. Such types of cells are also known as electrolytic cells.

The significant industrial applications of electrolysis are as follows

1. Electrometallurgy
2. Electroplating
3. Electrolytic Refining

5.3.1 Electrometallurgy

It is the extraction of metal from its ore by electrolysis as shown in [3.1.4 (C)]. Some active metals like sodium, magnesium, potassium and calcium are extracted by the electrolysis of their corresponding fused metal salts, while other metals are obtained from its aqueous solution.

Extraction of Sodium from Fused Sodium Chloride

In this electricity is passed through fused sodium chloride, using graphite electrode, In this process, graphite electrode does not actively participate in the chemical reactions taking place in the cell but only used for conduction of electrons (acting as inert electrode).Hence Sodium cations are migrated towards cathode and chloride anion migrated towards anode. These shows following chemical reactions. [Fig. 5.2]

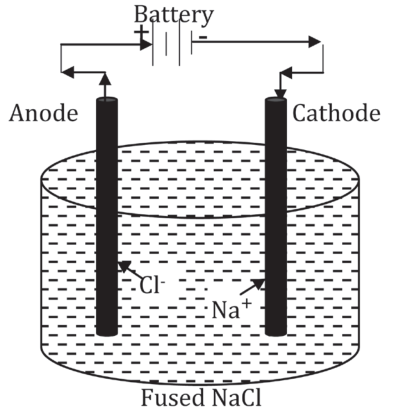


Fig. 5.2 Extraction of sodium

Reaction at Anode

Chloride ions loses electrons and converted into chlorine atom in the primary stage (first step)

Then two neutral chlorine combines with each other thus there is liberation of chlorine gas.

$Cl^{-} \longrightarrow Cl + e^{-}$	Oxidation Reaction (Primary stage)
$Cl^{-} \longrightarrow Cl + e^{-}$	Oxidation Reaction
$Cl + Cl \longrightarrow Cl_2\uparrow$	Secondary reaction

Reaction at Cathode

Electron which is lost by chloride ion is transferred from anode to cathode and Sodium ion from electrolyte accept the electrons and deposited at cathode.

$Na^{+} + e^{-} \longrightarrow Na$	Reduction reaction

In this way more active metal can be easily extracted from the fused salt.

5.3.2 Electroplating

The process of metallic coating of more resistant metal (or superior metal or less active metals like silver gold, nickel, chromium,copper etc.) on the surface of the base metal (or inferior metal or more active metal) with the help of electric current is called electroplating.

The purpose of electroplating is a) to protect the metal from corrosion, b) to decorate the ornaments and cutlery to increase the market price, and c) to repair the cracks and cavities developed in the damaged machinery part.

In this process, the article to be electroplated is cleaned thoroughly by the hot solution of alkali or soap to remove the grease or grit or dirt. Then it is treated with dilute acid to remove the oxide layer or other impurities that stickup to the article. The treatment with dilute acids is called acid pickling. Further, it is washed with water and then carefully polished by polishing paper. The cleaned article is then suspended into the electrolytic cell and mount as a cathode. An anode is a pure metal plate or rod whose coating is desired on the article and suspended in the cell.

The electrolyte is the metal salt solution of anodic metal with which the article is to be electroplated. On passing electric current, the metallic ions from the electrolyte get deposited on the article made as a cathode. The equivalent amount of anode gets dissolved in the form of metal ions and passes into an electrolyte. Smooth and brighter deposits are obtained i) at low temperature, ii) high current density, iii) high metal ion concentration of electrolyte and iv) at specific pH. Let us understand this with the help of example.

Electroplating of silver on the iron spoon is carried out in a rectangular tank of steel. The iron spoon, which is to be electroplated, is cleaned thoroughly by boiling with caustic soda to remove dirt or grit or grease. Further, it is washed with water until it is free from caustic soda. Then it is placed in an acid tank containing dilute acid to remove the oxide layer present on the spoon. Further, it is washed with water to remove excess acid and polished with polishing paper. Then iron spoon is made as a cathode, and the anode is made up of a pure silver metal plate[Fig. 5.3]. The anode and cathode are suspended in the electrolyte in the cell of potassium argentocynide K[Ag(CN)$_2$] on passing the direct electric current, at applied voltage, the iron spoon gets plated with smooth and brighter deposits of silver. Silver anode gets slowly dissolved in solution by giving Ag$^+$ ions

Reaction at Anode (Active Electrode)

$$\underset{\text{Silver anode}}{Ag} \longrightarrow Ag^+ + 1e^- \text{ (Oxidation)}$$

Reaction at Cathode (Inert Electrode)

$$\underset{\text{Silver ion electrolyte}}{Ag^+ + e^-} \longrightarrow \underset{\text{Silver metal}}{Ag} \quad \text{(Reduction)}$$

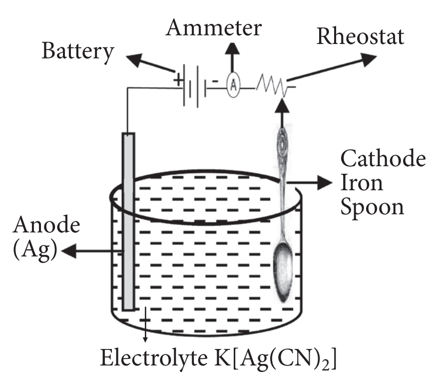


Fig. 5.3 Electroplating

Instead of discharging of the anion with lower discharge potential, anode metal is immersed into its own salt solution, therefore having a tendency to dissolve into solution

As silver metal rod/electrode has actively participated in the chemical reactions taking place in the solution, it is known as an active electrode. Size of anode –metal decreases. Electron loss by Ag metal is transferred from anode to cathode.

Electroplating

All cations from the electrolyte, like Ag^+, H^+ and K^+, migrate towards the cathode, but Ag^+ ions require lower discharge potential than H^+ and K^+, therefore, only Ag^+ gets deposited at the cathode. Iron spoon or inferior metal, is not actively participating in the reaction taking place in the cell and is only used for conduction of electrons.

The net result of the electrolysis

The concentration of Ag^+ remains constant throughout the process. As one metallic atom gets converted into one ion simultaneously, the cation Ag^+ ion from the electrolyte gets discharged at the cathode.

As anode is immersed into its own salt solution, it gets dissolved into solution, hence the size of the anode decreases during the process. As metallic cations are discharging at the cathode,the cathode size goes on increasing during the process.

5.3.3 Electrolytic Refining

Electrolytic refining is the process of extraction of metals from the impure metallic rod. In this electrolysis process, pure metal is obtained from an impure metal rod by passing an electric current. Impure metal in the form of a thick rod or plate is made as an anode, and a thin sheet of the same metal is made the cathode. The electrolyte is the solution of a salt of the metal to be refined. Using the required voltage, the anode of the impure metallic rod goes into solution in the form of metal ions. The electrolyte also breaks up into positively charged metal and negatively charged anions. Positively charged metal atoms get discharged at the cathode and deposited. Anode dissolves, and impurities get settled down below the anode, called anode mud. The cathode is refined metal, and it is washed, dried and put to use.

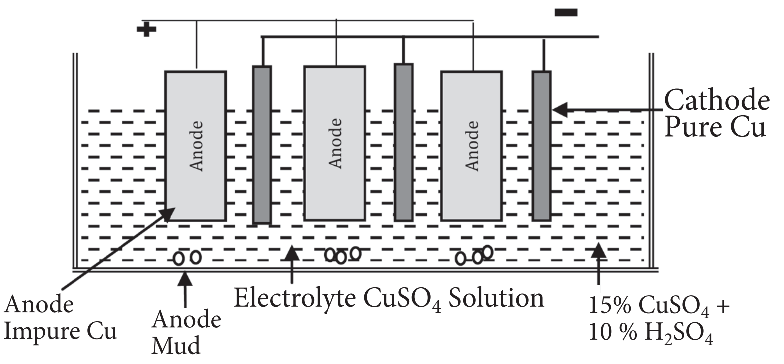


Fig. 5.4 Electrolytic Refining of Copper

The electrolysis process refines the metals like Zn, Cu, Sn, Ag, Al, etc. Impure copper obtained by the extraction process may contain about 3% to 5% impurities like S, As, Zn, Fe, Ni, Ag, Pt etc. Such impure copper is not fit to be used as an electrical conductor. The conductivity is appreciably lowered due to the traces of impurities present in it. Copper with 100% purity is required for electrical conductivity. Hence, crude copper is refined by the process called electro-refining. The electro-refining of copper is carried out in a large lead tank. Impure copper is cast into large plates suspended into the tank acts as anodes. Cathodes are thin plates of pure copper, and each is suspended between two plates of the anode. The electrolyte is a mixture of 15% copper sulphate solution, and 10% dilute sulphuric acid. For this process, direct current at low voltage is used [Fig. 5.4].

When current is passed, copper from impure copper anode with traces of more active metals like Zn, Fe, Ni present as impurities, go into the solution as metallic ions, whereas less active metals like Ag, Au, and Pt are not ionised but crumbles down from the anodes and settle below the anodes as anode mud. The electrolytes contain (Cu^{2+}) cupric ions and (SO_4^{2-})sulphate ions and H^+ ions and OH^- ions present in the electrolyte. After passing electricity through the electrolyte, ions are migrated towards oppositely charged electrodes, i.e. Cu^{2+} and H^+ ions are migrated or attracted or travelled towards cathode and SO_4^{2-} and OH^- ions are migrated towards the anode. The reaction starts after passing the electricity. Hence we can call such types of reactions as non-spontaneous chemical reactions. After passing electrical energy, chemical changes are taking place, hence it is called an electrolytic cell.

Reaction at the Anode (Active Electrode)

Cu	$\longrightarrow$	Cu^{2+}	+	2e-	(Oxidation Reaction)
Anode metal		Cupric ions enters into electrolyte		transferred from anode to cathode	

Reaction at the Cathode (Inert Electrode)

Cu^{2+}	+	$2e^-$	$\longrightarrow$	Cu	(Reduction Reaction)
Cupric ions(Blue) from the electrolyte		collected at cathode		Deposited at cathode (Red)	

The concentration of cupric ions (Cu^{2+}) remains constant throughout the process. The size of the anode goes on decreasing during the electrolysis, and that of the cathode is increasing. Impurities present in the anode are collected at the bottom of the anode, called anode mud. This method is helpful to extract 99.9 % pure copper, which is helpful for the development of printed circuit boards, motherboards, integrated circuits, pen drives, mobiles etc.

5.4 APPLICATIONS OF REDOX REACTIONS IN ELECTROCHEMICAL CELL

Redox reactions are characterised by the actual transfer of electrons from one electrode to another electrode. The electrode at which metal or ions loses electrons has been oxidised, while the electrode at which metal or ions accepts electrons has been reduced. The chemicals present in the cell reacts spontaneously with each other and produces electrical energy. Such types of cell are known as an electrochemical cell. Oxidation and reduction reactions are taking place in the cell. Some of the examples of electrochemical cells are as follows

1. Primary cell 2. Secondary cell

5.4.1 Primary Cell or Dry Cell

Primary cells are non-rechargeable and disposable. The electrochemical reactions in these batteries are non-reversible. The primary cell is also known as dry cell or pencil cell. It is not dry inside but it is pasty. Construction of primary cell and redox reactions taking place in the cells are given below.

Construction :

The dry cell consists of a graphite rod at the centre surrounded by a paste of manganese dioxide (MnO_2), ground carbon and water. This whole arrangement is placed in muslin cloth, which allows some ions to pass through it. At the top of the graphite rod steel cap is present, which represent the positive terminal. Around the muslin cloth, an electrolyte is present in the paste form. Zinc chloride and ammonium chloride paste are placed around the muslin cloth and covered with a metallic zinc container that acts as an anode representing a negative terminal. [Fig. 5.5].

Reaction at Anode (At Zn Electrode)

$Zn \xrightarrow{\qquad\qquad} Zn^{2+} + 2e^-$ (Oxidation Reaction)

$Zn + 4NH_3 \xrightarrow{\qquad\qquad} [Zn(NH_3)_4]^{2+}$

Reaction at Cathode

$2MnO_2 + 2NH_4^+ + 2e^- \xrightarrow{\qquad\qquad} Mn_2O_3 + 2NH_3 + 2H_2O$ (Reduction Reaction)

Oxidation and reduction reactions are taking place in the cell. As there is a transfer of electrons from anode to cathode,it represents the generation of electricity. Hence primary cell develops 1.5 V of electricity. As the cell generates electricity after the primary action of the chemicals hence known as the primary cell.

As chemicals are responsible for electricity generation, this cell is known as an electrochemical cell, and hence spontaneous chemical reactions are taking place. Zn is connected with zinc chloride dissolved in electrolyte paste, acting as an active electrode and graphite acting as an inert electrode. The dry cell does not have a long life, as acidic ammonium chloride corrodes the zinc container, even when it is not in use.

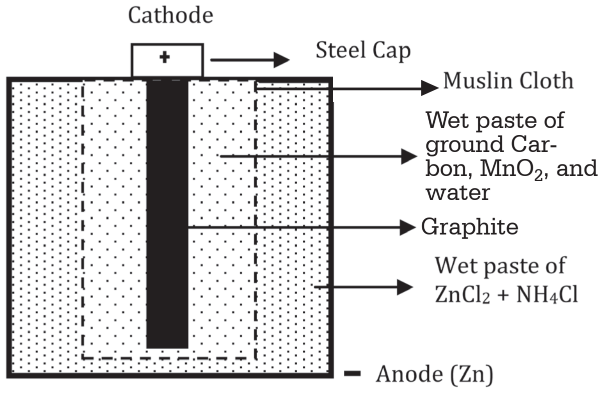


Fig. 5.5 Primary Cell

5.4.2 Secondary Cell

Electricity cannot be generated on a large scale by primary cells because it needs the replacement of exhausted electrodes by the new one. There are reversible cells in which chemical energy is transformed into electrical energy, and reverse transformation of electrical energy into chemical energy can be carried out. The spent electrodes can be regenerated by passing an electric current through the cell in the reverse direction. Such cells which allow electric energy to be stored and expanded are called storage cells or secondary cells or accumulators.

The process of storing electrical energy in an accumulator is called charging, while the reverse process of providing electrical energy is known as discharging. Several storage cells are connected in series to make up a storage battery. These storage cells are of different types like alkaline type, lead-acid storage cells, lithium-ion batteries.

(A) Lead- Acid Storage Cell or Lead Accumulator

Storage cells are operated in both ways as a voltaic cell and as an electric cell. When operating as a voltaic cell,it supplies electrical energy and is finally discharged. Then it must be recharged. When being recharged, the cell operates as an electrolytic cell. The advantage of the storage cell is its ability to work both ways, to receive electrical energy and supply it.

Lead Storage Cell

In a lead-acid storage cell, one of its electrodes is made of lead (Pb), and the other electrode is made of lead oxide (PbO_2,also known as lead dioxide).

The number of lead plates (-ve values) are connected in parallel, and a number of lead oxide plates (+ve values) are also connected in parallel. Lead plates are placed in between the two lead oxide plates. These plates are separated from adjacent ones by insulators such as a strip of glass or rubber, or wood. These are then immersed in 20% dilute H_2SO_4 (with specific gravity 1.15 at 25°C) [Fig 5.6].

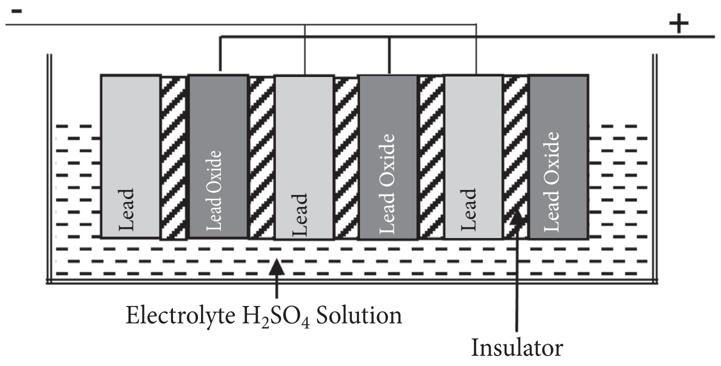


Fig. 5.6 Lead Acid Storage Cell

Discharging

When the cell is operating as the voltaic cell, i.e. it supplies electrical energy, then it is said to be discharging. The lead electrode enters into solution with the formation of lead ions. Therefore, oxidation takes place at the lead electrode.

Reactions at Lead (Pb) Electrode

$$Pb \longrightarrow Pb^{++} + 2e^- \qquad \text{(Oxidation Reaction)}$$

Active electrode Pb enters into the electrolyte in the form of ions by the loss of electrons. Formed lead ions react with sulphate ions to form lead sulphate precipitate.

$$Pb^{++} + SO_4^{-} \longrightarrow \underset{\text{Lead Sulphate Precipitate}}{PbSO_4 \downarrow}$$

Reactions at Lead oxide (PbO_2) Electrode

Lead oxide electrode also enters into the electrolyte in ionic form by accepting electrons from the external circuit. Hence reduction reaction occurs at the lead oxide electrode. Hence oxidation state of Pb changes from +4 to +2.

$$\underset{(4+)}{PbO_2} + 2e^- + \underset{(2+)}{4H^+} \longrightarrow Pb^{++} + 2H_2O \qquad \text{(Reduction Reaction)}$$

Lead ions formed react with sulphate ions from the electrolyte to form lead sulphate precipitate.

$$Pb_2^+ + SO_4^{2-} \longrightarrow \underset{\text{Lead Sulphate}}{PbSO_4}$$

So redox reaction in lead storage cell is

$$Pb + PbO_2 + 4H^+ + 2SO_4^{2-} \longrightarrow 2PbSO_4 + 2H_2O + \text{Energy}$$

During discharging, lead and lead oxide electrodes slowly dissolve in the electrolyte, releasing Pb^{2+}. The amount of lead sulphate precipitate and amount of water increases in the electrolytes during discharging while the percentage of H_2SO_4 decreases during discharging. A pair of Pb and PbO_2 gives 2 Volt of electricity. It gives 2 Volt of electricity during fully charged conditions,gradually decreasing during discharging up to 1.6 to 1.7 Volt. Hence, to increase the battery's voltage capacity, the number of Pb-PbO_2 electrode pairs is to be increased and connected in series.

Charging

When both electrodes are covered with lead sulphate, the cell stops functioning as a voltaic cell(electrochemical cell). Then it is necessary to recharge it. So the reactions taking place during discharging are reversed by passing external electromotive force (e.m.f.)greater than 2 volts from an external supply, hence the cell is called an electrolytic cell. Non-spontaneous chemical reactions will take place

Reactions at Pb (Lead) Electrode

Pb^{2+} ions are present in the electrolyte as $PbSO_4$.

$Pb^{2+} + 2e^- \xrightarrow{\hspace{2cm}} Pb$ (Reduction Reaction)

Regeneration of electrode

Reactions at PbO_2 (Lead oxide) Electrode

$\underset{(2+)}{Pb^{2+}} + 2H_2O \xrightarrow{\hspace{2cm}} \underset{(4+)}{PbO_2} + 2e^- + 4H^+$ (Oxidation Reaction)

Regeneration of PbO_2 electrode

Hence net reaction during charging is

$$2PbSO_4 + 2H_2O + \text{Energy} \xrightarrow{\hspace{2cm}} Pb + PbO_2 + 4H^+ + 2SO_4^{2-}$$

The redox cell reaction during discharging and charging can be shown as

$$PbO_2 + Pb + 2H_2SO_4 \underset{\text{Charging}}{\overset{\text{Discharging}}{\rightleftharpoons}} 2PbSO_4 + 2H_2O$$

During the process of charging, the electrodes of the cell are restored to their original conditions. It is observed that during discharging operation, the concentration of acid (H_2SO_4) decreases, while the concentration of acid increases during charging operation.

We will be learning in-depth about the determination of voltage generated from a chemical reaction using Daniel cell through practical performance mentioned in detail at the end of this unit.

Table 5.2 Difference between Electrolytic cell and Electrochemical Cell

Electrolytic Cell	Electrochemical Cell
It converts electrical energy into chemical energy.	It converts chemical energy into electrical energy.
Electricity is consumed. Require source of energy.	Produce electricity, it is a source of energy.
Redox reactions are non-spontaneous chemical reactions	Redox reactions are spontaneous chemical reactions.
Anode (+ve) terminal oxidation take place	Anode (-ve) terminal oxidation take place
Cathode (-ve) terminal reduction take place	Cathode (+ve) terminal reduction take place

(B) Fuel Cell

Fuel cell is an electrochemical cell that can convert the chemical energy contained in a readily available fuel oxidant system into electrical energy by an electrochemical process, in which fuel is oxidised at the anode. Similar to any other electrochemical cell, the fuel cell consists of an electrolyte and two electrodes. However, the fuel and the oxidising agent are continuously and separately supplied to the cell's electrodes at which they undergo reactions. These primary cells are capable of supplying current as long as the reactants are supplied. We know that voltaic cells involve an oxidation reduction reaction.

Fuel cells work at high efficiency & the resulting emission levels are far below the permissible limits.

In a fuel cell, electrical energy is obtained without combustion from oxygen. Hence fuel cell converts the chemical energy of the fuel directly to electricity.

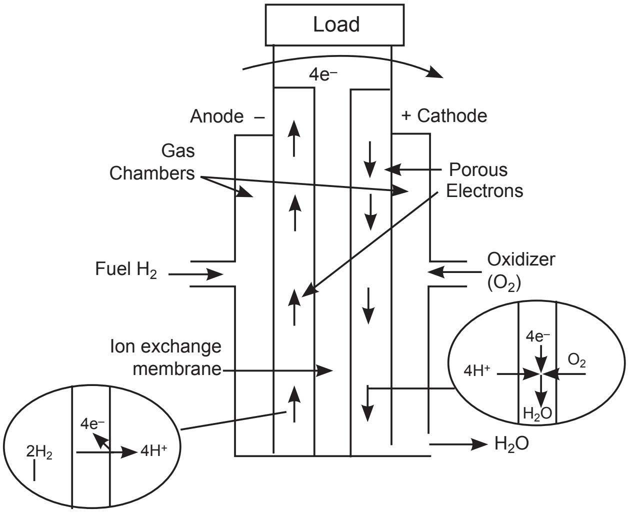


Fig. 5.7 Hydrogen - Oxygen Fuel Cell

The basic arrangement in the fuel cell can be represented as follows

Fuel | Electrode | Electrolyte | Electrode |oxidant

The essential process in the fuel cell is

Fuel + Oxygen $\longrightarrow$ Oxidation products +Electricity

One of the simplest and most successful fuel is the hydrogen-oxygen fuel cell. It consists essentially [Fig. 5.7] of an electrolytic solution such as 25%KOH solution and two inert porous electrodes. Hydrogen and oxygen gases are bubbled through the anode and cathode compartment, respectively, where the following reactions take place

At Anode $2H_2 \longrightarrow 4H^+ + 4e^-$

$4H^+ + 4OH^- \longrightarrow 4H_2O$

At Cathode $O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$

Redox $2H_2 + O_2 \longrightarrow 2H_2O$

The standard emf of the cell, E°=E°ox + E°red = 0.83V + 0.40 V = 1.23 V

In actual practice, the emf of the cell is 0.8 to 1.0 V. Usually, large number of these cells are stacked together in series to make a battery called fuel cell battery or fuel battery.

Hydrogen gas reacts with electrolytes and solid conducting structures to produce $2H^+$ ions. Two protons react with hydroxyl ions of the electrolyte to form water, which dilutes the KOH electrolyte. Two electrons are made available to the external circuit. The hydroxyl ions which are thus used up are replenished from the cathode reaction, in which O_2 reacts with two water to produce $4OH^-$ ions, taking up the four electrons from the outer circuit. These facts are reflected in the cell reactions given above.

The electrodes must meet requirements i) as good conductors, ii) be good electron source, iii) not deteriorated by electrolyte, heat or electrode reactions, and iv) be an excellent catalyst for the reactions that take place on their surfaces. When hydrogen is used as the fuel, the electrodes are made of either graphite impregnated with finely divided platinum, or a 75/75 alloy of palladium and silver, or nickel. The secret of successful fuel cells probably lies in developing expensive electrodes that are powerful catalysts for electrode reactions. Electrolytes used most often are aqueous KOH or H_2SO_4 or ion exchange resin saturated with water. For low temperature operating fuel battery (–54^0C to 72^0C), potassium thiocyanate dissolved in liquid ammonia is employed.

Applications

Hydrogen oxygen fuel cells are used as an auxiliary energy source in space vehicles, submarines or other military vehicles. In H_2-O_2 fuel cells, the product water proved to be a valuable source of freshwater by the astronauts.

(C) Solar Cell

Solar energy is obtained from the sun by conversion to electrical energy directly using a photovoltaic cell.[Fig 5.8] shows a photovoltaic cell in which a p-type semiconductor (such as Si doped with B) is in contact with an n-type semiconductor (such as Si doped with P).

The sun light travels in packets of energy called quanta or photons. The electric current is generated inside the depletion zone of the p-n junction diode. When a photon of light is incident and absorbed by one of these atoms in the n-type silicon material, it will dislodge an electron, creating a free electron and a hole. The free electron and hole have sufficient energy to jump out of the depletion zone. The electron is attracted to the positive charge of the p-type material and travels through the external circuit, creating a flow of electric current. The hole created by the dislodged electron is attracted to the negative charge of n-type material and migrates to the back electrical contact. Electrons move from n-type material and enters into p-type material from back electrical contact where it combines with the hole which restores electrical neutrality

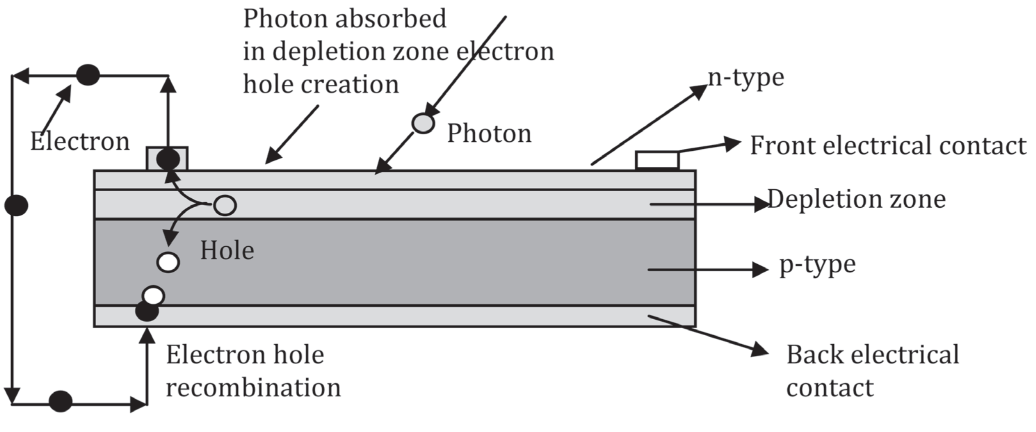


Fig. 5.8 Photovoltaic Solar Cell

Generally a solar panel is made up of 32, 36, 48, 60, 72 and 96 photovoltaic cells. The solar array is a system made up of a group of solar panels connected together. A solar panel comprising 32 cells typically can produce 14.72 volts output (each cell producing about 0.46 volt of electricity).

Interesting Fact : Electrochemical sensors are used for the detection of oxygen and other toxic gases. Precisely, they measure the concentration of a specific gas within an external circuit. Practically this can be done by the method of oxidation or reduction reactions. These reactions generate the positive or negative current flowing through said external circuit.

5.5 Corrosion – An Introduction

Surface of many metals is easily attacked when exposed to atmosphere. They react with air or water present in the environment and form undesirable compounds on their surfaces. These undesirable compounds are generally oxides.

Thus the process of deterioration or destruction and consequent loss of a solid metallic material through an unwanted chemical, electrochemical and biochemical attack by its environment at its surface is called corrosion. Thus corrosion is a reverse process of extraction of metals. Metals and alloys are used as fabrication or construction materials in engineering. If the metals or alloy structures are not properly maintained, they deteriorate slowly by the action of atmospheric gases, moisture and other chemicals. This phenomenon of destruction of metals and alloys is known as corrosion.

Examples :

(i) Rusting of Iron – When iron is exposed to the atmospheric conditions, a layer of reddish scale and powder of Fe_3O_4 is formed.

(ii) Green Film on Copper - [$CuCO_3 + Cu(OH)_2$] on the surface of copper when exposed to moist air containing CO_2.

Consequences of corrosion

The process of corrosion is slow and occurs only at surface of metals but the losses incurred are enormous. Destruction of machines, equipment, building materials and different types of metallic products, structures etc. Thus the losses incurred are very huge and it is estimated that the losses due to corrosion are approximately 2 to 2.5 billion dollars per annum all over the world. There are many social and economic consequences of corrosion. The economic and social consequences of corrosion include the following

- Due to formation of corrosion product over the machinery, the efficiency of the machine is reduced or reach to the stage of failure which leads to plant shut down.
- Corrosion releases the toxic products which affect the health of mankind.

Causes of Corrosion

Metallic Corrosion

The metals are extracted from their ores. During the extraction, ores are reduced to their metallic states by applying energy in the form of various processes. In the pure metallic state, the metals are unstable as they are considered in excited state (higher energy state). Therefore, as soon as the metals are extracted from their ores, the reverse process begins and form metallic compounds, which are thermodynamically stable (lower energy state). Hence, when metals are used in various forms, they are exposed to environment, these exposed metal surface begin to decay or convert into more stable compounds. This is the basic reason for metallic corrosion.

$$\text{Metal} \xrightleftharpoons[\text{Metallurgy-Reduction}]{\text{Corrosion-Oxidation}} \text{Metallic Compound + Energy}$$

Although corroded metal is thermodynamically more stable than pure metal but due to corrosion, the useful properties of a metals like malleability, ductility, hardness, lustre and electrical conductivity are lost.

5.5 A) Types of Corrosion

The primary factors which initiate corrosion of metals are atmospheric air and water

Based on the environment, corrosion is classified into

(i) Dry or Chemical Corrosion (ii) Wet or Electrochemical Corrosion

5.5.1 Dry or Chemical Corrosion

It occurs in the absence of moisture or conducting electrolyte medium. This type of corrosion is due to the direct chemical attack of metal surfaces by the atmospheric gases such as oxygen, halogen, hydrogen sulphide, sulphur dioxide, nitrogen, anhydrous inorganic liquid etc. The chemical corrosion is defined as the direct chemical attack of metals by the atmospheric gases present in the environment. This causes to form an oxide layer over the surface of metals and alloys.

Example :

(i) Silver materials undergo chemical corrosion by atmospheric H_2S gas.

(ii) Iron metal undergo chemical corrosion by HCl gas.

Types of Dry or Chemical Corrosion

5.5.1(A) Corrosion by Oxygen or Oxidation corrosion [Fig. 5.9]

5.5.1(B) Corrosion by Hydrogen [Fig. 5.10]

5.5.1(C) Liquid Metal Corrosion

We will be studying here the first two types of corrosion

(A) Corrosion by Oxygen or Oxidation Corrosion

- Oxidation Corrosion is brought about by the direct attack of oxygen at low or high temperature on metal surfaces in the absence of moisture.
- Alkali metals (Li, Na, K etc.,) and alkaline earth metals (Mg, Ca, Sn, etc.,) are rapidly oxidized at low temperature.
- At high temperature, almost all metals (except Ag, Au and Pt) are oxidized.

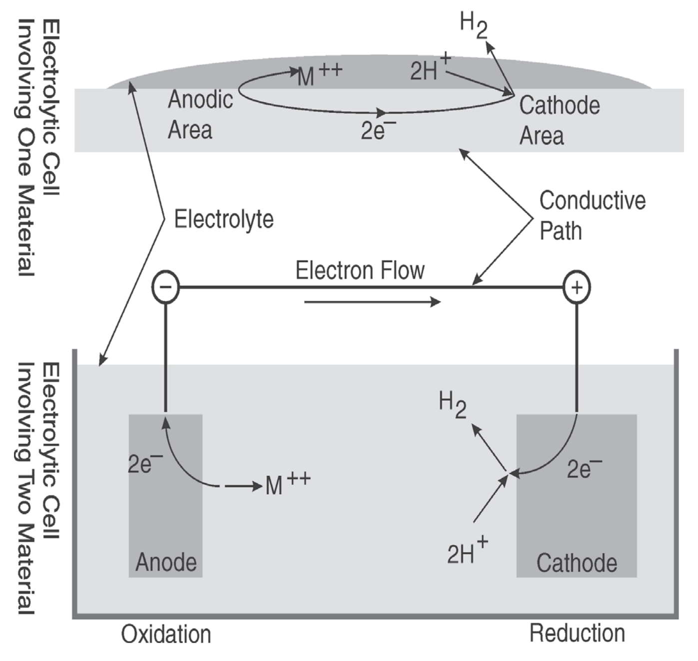


Fig 5.9 Corrosion by Oxygen

- The nature of the oxide formed plays an important role in oxidation corrosion process.
- Metal + Oxygen → Metal oxide (corrosion product)
- When oxidation starts, a thin layer of oxide is formed on the metal surface and the nature of this film decides the further action. Different metals form different types of layers with oxygen, as mentioned below

(i) Stable layer - A Stable layer is fine grained in structure and can get adhered tightly to the parent metal surface. Hence, such layer, which cuts-off penetration of attaching oxygen to the underlying metal behaves as protective coating thereby shielding the metal surface. The oxide films on Al, Sn, Pb, Cu, Pt, etc., are stable, tightly adhering and impervious in nature.

(ii) Unstable Oxide layer : This is formed on the surface of noble metals such as Ag,Au, Pt. The metallic state is more stable than oxide hence, it decomposes back into the metal and oxygen. Hence, oxidation corrosion is not possible with noble metals.

(iii) Volatile Oxide layer : The oxide layer film volatilizes as soon as it is formed. Hence, always a fresh metal surface is available for further attack. This causes continuous corrosion. MoO_3 is volatile in nature.

(iv) Porous layer : The layer having pores or cracks. In such a case, the atmospheric oxygen have access to the underlying surface of metal, through the pores or cracks of the layer, thereby the corrosion continues unobstructed, till the entire metal is completely converted into its oxide.

5.5.2 Wet or Electrochemical Corrosion

Electrochemical corrosion involves:

i) The formation of anodic and cathodic areas or parts in contact with each other

ii) Presence of a conducting medium

iii) Corrosion of anodic areas only and

iv) Formation of corrosion product somewhere between anodic and cathodic areas.

This involves flow of electron-current between the anodic and cathodic areas.

At anodic area oxidation reaction takes place (liberation of free electron). Hence anodic metal is destroyed by either dissolving or assuming combined state (such as oxide, etc.). Hence corrosion always occurs at anodic areas.

M (metal) → M^{n+}+ne-

M^{n+}(metalion) → Dissolves in solution & forms compounds such as oxide

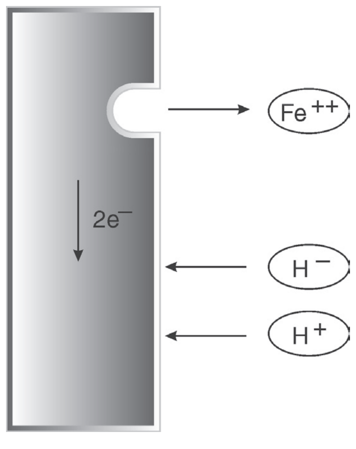


Fig. 5.10 Wet or Electrochemical Corrosion

At cathodic area, reduction reaction takes place (gain of electrons). Cathodic reactions do not affect the cathode, since most metals cannot be further reduced. So at cathodic part, dissolved constituents in the conducting medium accepts the electrons to form some ions like OH^{-} and O^{2-}

Depending on the nature of the corrosive environment, cathodic reaction consumes electrons with either by

(a) Evolution/Liberation of Hydrogen

(b) Absorption of Oxygen

(A) Hydrogen Evolution / Liberation Type

All metals above hydrogen in the electrochemical series have a tendency to get dissolved in acidic solution with simultaneous evolution of hydrogen. It occurs in acidic environment. Consider the example of iron

At anode : $Fe \longrightarrow Fe^{2+} + 2e^-$

These electrons flow through the metal, from anode to cathode, where H+ ions of acidic solution are eliminated as hydrogen gas.

At cathode : $2H^+ + 2e^- \longrightarrow H_2\uparrow$

The overall reaction is : $Fe + 2H^+ \longrightarrow Fe^{2+} + H_2$

We will be learning in depth about the determination of the weight change when two dissimilar metals are connected and immersed in the solution through practical performance mentioned at the end of this unit.

(B) Oxygen Absorption Type

Rusting of iron in neutral aqueous solution of electrolytes like NaCl solution in the presence of atmospheric oxygen is a common example of this type of corrosion. The surface of iron is usually coated with a thin film of iron oxide. However, if this iron oxide film develops some cracks, anodic areas are created on the surface; while the well metal parts acts as cathodes.

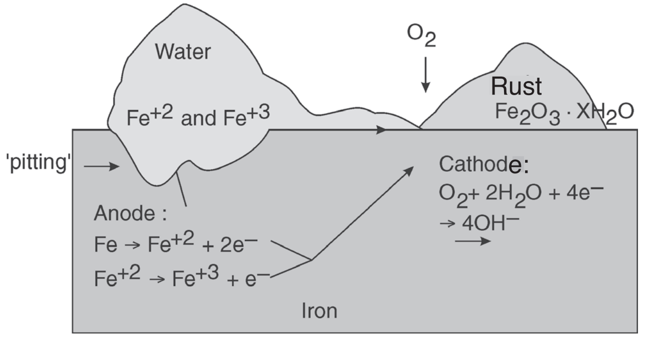


Fig. 5.11 Oxygen Absorption Type

At Anode : Metal dissolves as ferrous ions with liberation of electrons [Fig. 5.11].

$Fe \longrightarrow Fe^{2+} + 2e^-$

At Cathode : The liberated electrons are stopped by the dissolved oxygen.

$\frac{1}{2} O2 + H_2O + 2e^- \longrightarrow 2OH^-$

The Fe^{2+} ions and OH^- ions diffuse and form, ferrous hydroxide.

$$Fe^{2+} + 2OH^- \longrightarrow \underset{ppt}{Fe(OH)_2}$$

If enough oxygen is present, ferrous hydroxide is easily oxidized to ferric hydroxide.

$4Fe(OH)_2 + O_2 + 2H_2O \longrightarrow 4Fe(OH)_3$ (Yellow rust $Fe_2O_3.H_2O$)

If the supply of oxygen is limited, the corrosion product may be even black anhydrous magnetite, Fe_3O_4

(C) Difference between Dry/Chemical and Electrochemical Corrosion

The difference between chemical and electrochemical corrosion is mentioned in table 5.3

Table 5.3 Difference between Dry/Chemical and Wet/Electrochemical Corrosion

Sl. No.	Chemical Corrosion	Electrochemical Corrosion
1.	It occurs in dry condition.	It occurs in the presence of moisture or electrolyte.
2.	It is due to the direct chemical attack of the metal by the environment.	It is due to the formation of a large number of anodic and cathodic areas.
3.	Even a homogeneous metal surface gets corroded.	Heterogeneous (bimetallic) surface alone gets corroded.
4.	Corrosion products accumulate at the place of corrosion	Corrosion occurs at the anode while the products are formed elsewhere.
5.	It is a self-controlled process.	It is a continuous process.
6.	It adopts adsorption mechanism.	It follows electrochemical reaction.
7.	Example-Formation of mild scale on iron surface	Rusting of iron in moist atmosphere

5.6 FACTORS INFLUENCING RATE OF CORROSION

Following factors influence the rate of corrosion

5.6.1 Nature of metals

5.6.2 Nature of the corroding environment

5.6.1 Nature of Metals

Many factors related to nature of metals contribute to the rate of corrosion. Some of them are -

(i) Position in Galvanic Series The metal higher in series is more active and suffer corrosion. The rate and extent of corrosion is directly proportional to electrode potential difference between them.

(ii) Over Voltage The over voltage of a metal in a corrosive environment is inversely proportional to corrosion rate. For example, the over voltage of hydrogen is 0.7 v. When zinc metal is placed in 1 M sulphuric acid, the rate of corrosion is low. When we add small amount of copper sulphate to dilute sulphuric acid, the hydrogen over voltage is reduced to 0.33V. This results in the increased rate of corrosion of zinc metal.

(iii) Purity of Metal Impurity of a metal generally causes heterogeneity and form minute electrochemical cells and the anodic part gets corroded. For e.g. Zn metal containing impurity such as Pb or Fe undergoes corrosion. The rate and extent of corrosion increases with extent of impurities.

(iv) Nature of the Surface Film When metals are exposed to atmosphere, practically all metals get covered with a thin surface film of metal oxide. The ratio of the volume of metal oxide to the metal is known as specific volume ratio. Greater the specific volume ratio, lesser is the oxidation corrosion rate. For e.g. the specific volume ratio of Ni, Cr, W are 1.6, 2.0 and 3.6 respectively. Rate of oxidation corrosion is least for tungsten (W).

(v) Nature of the Corrosion Product Following factors contribute to the nature of corrosion Product.

- **Solubility of Corrosion Products.** If the corrosion product is soluble in the corroding medium, then corrosion proceeds at a faster rate other wise if it is insoluble, corrosion will be suppressed e.g. $PbSO_4$ formation in case of Pb in H_2SO_4.
- **Volatility of Corrosion Products.** If the corrosion product is volatile, it evaporates as soon as it is formed, thereby leaving the underlying metal surface exposed for further attack. This causes rapid and continuous corrosion. For example, Mo forms MoO_3 volatile oxide.

(vi) Physical State The rate of corrosion is influenced by physical state of the metal (such as grain size, orientation of crystals, stress, etc). The smaller the grain size of the metal or alloy, the greater will be its solubility and hence greater will be its corrosion. Moreover, areas under stress, even in a pure metal, tend to be anodic and corrosion takes place at these areas.

5.6.2 Nature of the Corroding Environment

(i) Temperature With increase of temperature, the corrosion rate also increases because the reaction as well as diffusion rate of ions in the corrosion medium increases.

(ii) Humidity of Air The rate of corrosion will be more when the relative humidity of the environment is high. The moisture acts as a solvent for oxygen, carbon dioxide, sulphur dioxide etc. in the air to produce the electrolyte which is required for setting up a corrosion cell.

(iii) Effect of pH Rate of corrosion increases with decrease in pH.

If $pH>10$, the rate of corrosion ceases due to the formation of protective coating of hydrous oxides on the metal.

If pH is between 3-10, the rate of corrosion depends upon the presence of oxygen on the cathodic area for reduction. Higher the concentration of O_2, higher the rate of corrosion. If $pH<3$ rate of corrosion is high even in the absence of air due to evolution of hydrogen at the cathodic region.

(iv) Presence of Impurities in Atmosphere Atmosphere in industrial areas contains corrosive gases like CO_2, H_2S, SO_2 and fumes of HCl, H_2SO_4 etc. In presence of these gases, the acidity of the liquid adjacent to the metal surfaces increases and its electrical conductivity also increases, thereby the rate of corrosion increases.

(v) Presence of Suspended Particles in Atmosphere In case of atmospheric corrosion:

if the suspended particles are chemically active in nature (like NaCl, Ammonium sulphate), they absorb moisture and act as strong electrolytes, thereby causing enhanced corrosion.

if the suspended particles are chemically inactive in nature (e.g., charcoal), they absorb sulphur gases and moisture and slowly enhance corrosion rate.

(vi) Conductivity rate of corrosion increases with increase in conductance of medium.

For example, rate of corrosion of metal will be higher in wet atmosphere than dry atmosphere due to more conductance. Similarly, metal undergo rapid corrosion in ocean water than in river water.

5.7 INTERNAL CORROSION PREVENTIVE MEASURES

Some of the internal corrosion preventive measures such as purification of metals, alloying and heat treatment are given below

5.7.1 Purification of Metals

The impurities present in metal decreases their corrosion resistance. Hence purification of metals may be carried out by appropriate methods of purification. Based on the properties and composition of different metals to be purified, different methods of purification of metals are employed as mentioned below-

- Distillation
- Liquation
- Poling
- Electrolysis
- Zone Refining
- Vapour Phase Refining
- Chromatographic Methods

5.7.2 Alloying

Use of corrosion resistant alloys should be used for prevention of corrosion. Several corrosion resistant alloys have been developed for specific purposes and environment.

For example,

(a) Stainless steel containing chromium produce an exceptionally coherent oxide film which protects the steel from further attack.

(b) Cupro -nickel (70% Cu + 30% Ni) alloys are now used for condenser tubes and for bubble trays used in fractionating column in oil refineries.

(c) Highly stressed Nimonic alloys (Ni -Cr-Mo alloys) used in gas turbines are very resistant to hot gases.

Alloying Steel - Alloyed steel is one of the most effective corrosion prevention methods. Corrosion resistance of various metals can be improved by alloying with corrosion resistant nickel and oxidation-resistant chromium. This results in an alloy that can be used in oxidizing and reducing chemical environments. Due to the presence of alloying elements, stainless steel is corrosion resistant than carbon steels. Minimum 10.5% chromium in its formulation makes stainless steel really ‘stainless’. During preparation of these steel, chromium-rich oxide barrier is formed that seals the surface, offering better corrosion resistance than other alloy steels. Aside from chromium, the following alloying elements are common additions to stainless steel formulations.

- Nickel makes the austenitic structure more stable, adds ductility and increases high-temperature strength and corrosion resistance.
- Manganese also stabilizes the austenitic structure, and it improves hot working properties.
- Molybdenum increases resistance to corrosion from chlorides.
- Niobium protects against inter granular corrosion and also helps prevent the formation of chrome carbides.
- Niobium and titanium both assist carbon in reducing risk for inter granular corrosion and act as grain refiners.

You may also refer the composition, properties and uses of some of the alloys of copper, iron and aluminium, already mentioned in unit - 3, engineering materials of this text book.

5.7.3 Heat Treatment

Heat treatment is found to effect the corrosion rates. Both ferrous as well as non-ferrous metals undergo heat treatment before putting them to use. Heat treatments can be used to homogenize cast metal alloys to improve their hot workability, to soften metals prior to, and during hot and cold processing operations, or to alter their microstructure in such a way as to achieve the desired mechanical properties. Over the course of this process, the metal's properties such as electrical resistance, magnetism, hardness, toughness, ductility, brittleness and corrosion resistance will change.

Thermal treatment of metallic alloys are also used to alter the surface chemistry of a material. This is achieved by diffusing carbon, nitrogen and other gaseous or solid material on to the surface of the component. These processes are used to give defined surface hardness and to improve wear, corrosion and fatigue resistance.

Heat treatment is the process of heating and cooling metals, using different methods to obtain desired properties. The physical properties of steel change on heating and cooling. Following are some heat treatment methods by which steel of different properties are obtained.

(i) **Annealing** It is the process of heating steel to a bright red heat and then cooling it slowly. By this, steel becomes soft and pliable.

(ii) **Hardening or Quenching** It is the process of heating steel to bright redness and then cooling suddenly by putting in oil or water. By doing so, steel becomes very hard and brittle.

(iii) **Tempering** It is the process of heating the hardest steel to a temperature much below redness and cooling it slowly. The steel thus obtained is neither too hard nor too soft. It is also not so brittle.

The annealed specimen with coarser grain displayed better corrosion resistance. The corrosion rate results for annealed specimens were 35% lower than the other heat treated specimens. Heat treatment can be defined as a combination of heating and cooling operations applied to a metal or alloy in its solid state to obtain desired properties.

Metallurgist are constantly working to improve the outcomes and cost-efficiency of different new methods developed over a period of time. They are developing new schedules or cycles to produce a variety of grades referring to a different rate of heating, holding and cooling the metal. These methods, when followed meticulously, can produce metals of different standards with remarkable physical and chemical properties.

5.8 EXTERNAL CORROSION PREVENTIVE MEASURES

Corrosion process is very harmful and losses incurred are tremendous. Since the types of corrosion are numerous and the conditions under which corrosion occurs are so different, diverse methods are used to control corrosion. As the corrosion is a reaction between the metal or alloy and the environment, any method or corrosion control must be aimed at either modifying the alloy/metal or the environment.

5.8.1 Cathodic Protection

The metal to be protected is made as cathode thereby corrosion doesn't occur. There are two types of cathodic protection.

(A) Sacrificial Anodic Protection Method

In this method the metallic structure to be protected is connected by a wire to a more anodic metal, so that all the corrosion is concentrated at this more active metal [Fig. 5.12]. The more active metal itself gets corroded slowly, while the parent structure which is cathodic is protected. The more active metal so employed is called "sacrificial anode". Whenever the corroded sacrificial anode is consumed completely, it is replaced by a fresh one. Metals commonly employed as sacrificial anodes are Mg, Zn, Al and their alloys.

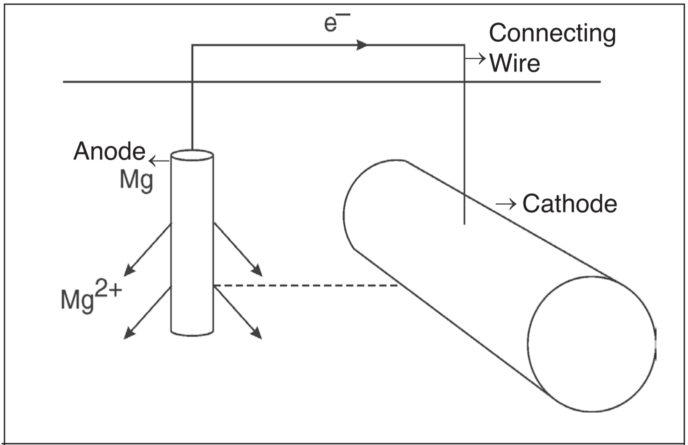


Fig. 5.12 Sacrificial Anodic Protection Method

For metallic coatings cathodic protection and anodic protection methods are employed under external corrosion protective measures.

Applications

Some of the applications are

(i) Protection of buried pipelines, underground cables from soil corrosion.

(ii) Protection from marine corrosion of cables, ship hulls, piers etc.

(iii) Insertion of magnesium sheets into the domestic water boilers to prevent the formation of rust.

(iv) Calcium metal is employed to minimize engine corrosion.

(B) Impressed Current Cathodic Protection

In this method an impressed current is applied in opposite direction to nullify the corrosion current and convert the corroding metal from anode to cathode. Usually the impressed current is derived from a direct current source (like battery or rectifier on AC line) with an inert anode, like graphite, high silica iron, scrap iron, stainless steel or platinum. Usually a sufficient DC is applied to an inert anode, buried in the soil (or immersed in the corroding medium) and connected to the metallic structure to be protected. The anode is composed of coke breeze or gypsum which enhance the electrical contact with the surrounding soil.

Impressed current cathodic protection has been applied to open water box coolers, water tanks, buried oil or water pipes, condensers, transmission line towers, laid up ships etc. This protection technique is useful for large structures for long term operations.

5.8.2 Anodic Protection

Galvanizing is commonly used for anodic protection.

(A) Galvanizing (Zinc Coating on Iron)

The process of coating a layer of zinc on iron by hot dipping is called as galvanizing [Fig. 5.13].

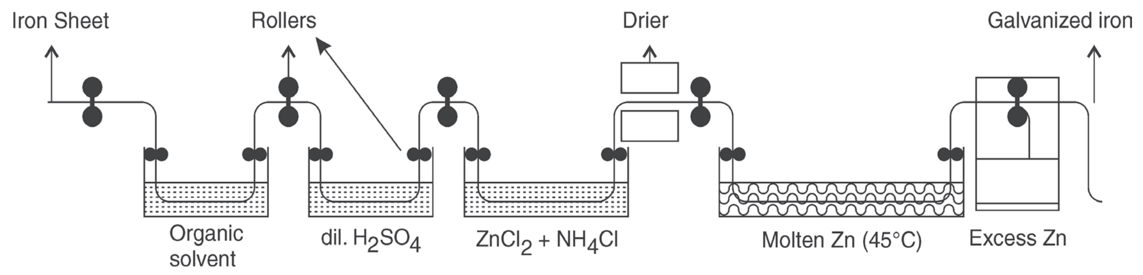


Fig. 5.13 Galvanizing (Zinc Coating on Iron)

Galvanizing process involves the following steps

(i) Iron sheet is passed through organic solvent to remove oil or grease present on it.

(ii) Then it is washed with dil. H_2SO_4 (pickling) to remove any rust (oxide layer) present on the surface

(iii) Then it is treated with a mixture of aqueous solution of zinc chloride ($ZnCl_2$) and ammonium chloride (NH_4Cl) which acts as flux and then dried.

(iv) The treated sheet is dried and dipped in molten zinc at 430-470°C.

(v) Excess zinc present on iron sheet is removed by rolling, wiping or passing blast of air.

Uses :

Galvanization is used for roofing sheets, buckets, bolts, nuts, nails, pipes etc. Galvanizing and tinning by hot dipping is more economical than electroplating. Hot dipping is limited to the coating of low melting point metals like Zn, Sn and Al over iron. But galvanized utensils cannot be used for preparing and storing food stuffs, especially acidic ones since zinc gets dissolved in all acids forming highly toxic compounds.

5.8.3 Organic Inhibitors

Inhibitors are organic or inorganic substances which decrease the rate of corrosion. Usually the inhibitors are added in small quantities to the corrosive medium. Inhibitors are classified as follows

- Anodic inhibitors (chemical passivators)
- Cathodic inhibitors (adsorption inhibitors)
- Vapour phase inhibitors (volatile corrosion inhibitors)

(A) Anodic Inhibitors

Inhibitors which retard the corrosion of metals by forming a sparingly soluble compound with a newly produced metal cations. This compound will then adsorb on the corroding metal surface forming a passive film or barrier.

Anodic inhibitors are used to repair

(i) the crack of the oxide film over the metal surface

(ii) the pitting corrosion

(iii) the porous oxide film formed on the metal surface.

Examples: Chromate, phosphate, tungstate, nitrate, molybdate etc.

(B) Cathodic Inhibitors

Depending on the nature of the cathodic reaction in an electrochemical corrosion, cathodic inhibitors are classified into

(a) In an acidic solution : The main cathodic reaction is the liberation of hydrogen gas, the corrosion can be controlled by slowing down the diffusion of H^+ ions through the cathode. e.g., Amines, Mercaptans, Thiourea etc.

$$2\,H^+ + 2e^- \xrightarrow{\hspace{3em}} H_2$$

(b) In a neutral solution : In a neutral solution, the cathodic reaction is the adsorption of oxygen or formation of hydroxyl ions.

The corrosion is therefore controlled either by eliminating oxygen from the corroding medium or by retarding its diffusion to the cathodic area.

The dissolved oxygen can be eliminated by adding reducing agents like Na_2SO_3.

The diffusion of oxygen can be controlled by adding inhibitors like Mg, Zn or Ni salts.

e.g. Na_2SO_3, N_2H_4, Salts of Mg, Zn or Ni.

$$\tfrac{1}{2}\,O_2+H_2O+2e^- \xrightarrow{\hspace{3em}} 2OH^-$$

(C) Vapour Phase Inhibitors

These are organic inhibitors which are readily vapourised and form a protective layer on the metal surface. These are conveniently used to prevent corrosion in closed spaces, storage containers, packing materials, sophisticated equipments etc.

Examples are Dicyclohexyl ammonium nitrate, dicyclohexyl ammonium chromate, benzotriazole, phenylthiourea etc.

SOLVED PROBLEMS

5.1 : On passing the current of 0.5 ampere through a solution of salt of a metal for 32 minutes 0.3158g of metal was deposited What is the electro chemical equivalent of metal deposited.

Sol.: Given

I= 0.5 ampere, t= 32×60 seconds, W= 0.3158 g, As we know W= Z I t

After rearranging the equations

$$Z=\frac{W}{I\,t} \qquad Z = \frac{0.3158}{(0.5 \times 32 \times 60)}$$

$Z=3.29 \times 10^{-4}$ g/C

Electro Chemical Equivalent (E.C.E.) $=3.29 \times 10^{-4}$ g/C

5. 2 : On passing a current of 0.6 A through a solution of salt of copper for 20 minuets 0.24 g of copper was deposited. What is the equivalent weight of Copper?

Sol.: Given

I = 0.6 ampere, t= 20 minutes = 20 × 60 seconds, W= 0.24 g of copper deposited, Chemical equivalent or Equivalent weight of Copper = ?

For that first of all we have to

Calculate

Electro Chemical Equivalent (E.C.E.)=Z=?

From, Faraday's First law of electrolysis W= $\frac{W}{I\,t}$

After rearranging the equations

$Z=\frac{W}{I\,t}$ $Z=\frac{0.24}{0.6 \times 20 \times 60}$

$Z=3.33 \times 10^{-4} g/C$

Chemical Equivalent = 96500 × E.C.E. = 96500 × 3.33 × 10^{-4} =31.84 g

Hence Chemical equivalent = Equivalent weight=31.84 g

5.3 : A given quantity of electricity is passed through two cells containing copper sulphate and silver nitrate solutions respectively. If 0.99 g of silver and 0.29 g of copper are deposited, find the equivalent weight of silver when that of copper is 31.6.

Sol.: Weight of silver deposited =0.99 g, wt. of copper deposited =0.29 g,equivalent weight of copper =31.6 g, Equivalent weight of silver =?

According to Faraday's second law of electrolysis, =

$$\frac{\text{Wt. of Silver deposited}}{\text{Wt. of Copper deposited}} = \frac{\text{Equivalent Wt. of Silver}}{\text{Equivalent Wt. of Copper}}$$

$$\frac{0.99}{0.29} = \frac{\text{Equivalent Wt. of Silver}}{31.6}$$

Equivalent Weight of silver = $\frac{0.99 \times 31.6}{0.29}$ Equivalent Weight of silver = 107.8 g

UNIT SUMMARY

- Weight of substance deposited or liberated at an electrode is directly proportional to quantity of electricity passed through the electrolytes.
- When same amount (quantity) of electricity passed through different electrolytes connected in series then weight of substance deposited or liberated at respective electrode is directly proportional to equivalent weight of substance.
- Redox reactions are characterised by the actual transfer of electrons from one electrode to another electrode.
- Electrolytic refining is the process of extraction of metals from the impure metallic rod. Some of the examples of electrochemical cells are as follows

  A) Primary cell B) Secondary cell C) Fuel Cell D) Solar cell

- The process of deterioration or destruction and consequent loss of a solid metallic material through an unwanted chemical, electrochemical and biochemical attack by its environment at its surface is called corrosion.

EXERCISES

5.1 Classify the following as strong electrolyte and weak electrolyte
i) H_2SO_4 ii) HNO_3 iii) NH_4OH iv) HCl v) CH_3COOH vi) NaCl

5.2 State Faraday's first and second laws of electrolysis.

5.3 List the industrial applications of electrolysis.

5.4 Explain with the help of diagram the process of electroplating.

5.5 Explain with the help of diagram the process of electrorefining.

5.6 Explain construction and working of primary cell.

5.7 Explain construction, working and reactions involved in lead acid storage cell.

5.8 Write the importance of fuel cell and give its application.

5.9 Differentiate between chemical and electrochemical corrosion.

5.10 List the factors influencing the rate of corrosion.

5.11 Explain hydrogen evolution / liberation type corrosion occurs in the electrochemical corrosion.

5.12 Write down the internal corrosion preventing measures.

5.13 Write sacrificial anode protection method as measure of preventing external corrosion.

5.14 Explain the galvanization of iron with the help of labelled diagram.

PRACTICALS

1. CONDUCTIVITY OF WATER

PRACTICAL STATEMENT

Determine the conductivity of given water sample.

PRACTICAL SIGNIFICANCE

Conductivity of water is important as it helps us to know the amount of dissolved substances, chemicals, & minerals present in the water. Higher amounts of these impurities will lead to a higher conductivity. Conductivity is useful as a general measure of water quality. Conductivity is mainly used to estimate the concentrations of dissolved salts in the water. Important applications of conductivity measurement are in water treatment, leak detection, interface detection and desalination.

RELEVANT THEORY

Conductivity is the ability of a solution to conduct electric current. Conductivity is measured with a probe and meter. Conductivity (G) is inverse of resistivity (R) is determined from the voltage and current values according to ohms law R=V/I then G=1/R=I/V. The meter converts the probe measurement to micro mhos per centimeter and displays the result.

Conductivity is measured in micromho/cm(μmho/cm) or millimho/cm (mmho/cm) or milisiemen/m (mS/m) 1mS/m=10 μmho/cm

PRACTICAL OUTCOMES (PrOs)

PrO1 : Weigh accurately the given sample in electronic balance.
PrO2 : Prepare standard solution of given sample of defined molarity and normality.
PrO3 : Calibrate the conductivity meter.
PrO4 : Determine the conductivity of water samples from different sources for enabling its use in different applications.

8.5 PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)

8.6 RESOURCES, CHEMICALS AND GLASSWARE REQUIRED

- **Resources** Conductivity meter (Range-0 to 20, 200μS accuracy ±1% range) Magnetic stirrer (250-1250 rpm)
- **Chemicals** (AR Grade) 0.1N KCl solution, water sample
- **Glasswares** (Borosil) Beaker (100ml), Glass rod, Standard flask

8.7 SAFETY PRECAUTIONS

1. Switch on the conductivity meter for at least 30 minutes before starting the experiment so that the instrument gets stabilizes.
2. Calibrate the instrument.
3. Always prepare the calibration solution just before the start of the experiment.
4. Always dip the electrode in distilled water and do not expose it to air.

8.8 SUGGESTED PROCEDURE

1. Measure 50 mL of distilled water and transfer it to the beaker.
2. Weigh 0.7456 g of Potassium chloride.
3. Transfer the 0.7456 g of potassium chloride to the beaker containing distilled water. Stir continuously by the glass rod until it dissolves thoroughly.

4. Transfer the contents to the 100 mL standard flask.
5. Make up the volume up to 100 mL. By adding distilled water and shake the contents well. The prepared solution is used to calibrate the conductivity meter.

   Take 0.1N Potassium Chloride in a beaker. Switch on the magnetic stirrer and place the beaker on the stirrer. Insert the magnetic bead in the beaker.

   Place the electrode inside the solution. Select the calibration button and by using up and down keys, adjust the conductivity of the 0.1N potassium chloride solution to 14.12 millisiemens /cm at 30°C.
6. Now the conductivity meter is ready for the measurement of samples.

Procedure for Testing of Water Sample

1. Rinse the electrode thoroughly with deionised water and carefully wipe with a tissue paper
2. Measure 200 mL of water sample and transfer it to a beaker and place it on the magnetic stirrer.
3. Dip the electrode into the sample solution taken in a beaker and wait for a steady reading.
4. Make sure that the instrument is giving stable reading.
5. Note down the reading in the display directly, which is expressed in millisiemens.

OBSERVATIONS AND CALCULATIONS

Conductivity of given sample is……….............……millisiemens

RESULTS AND/OR INTERPRETATION

Conductivity of given sample is………….................millisiemens

CONCLUSIONS AND/OR VALIDATION

………………………………………………………………………………………..………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Whether conductivity affect aquatic life, explain.
2. Mention the applications of conductivity in everyday life.
3. Explain the importance of conductivity of water.
4. Relate pH with conductivity.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

8.15 SUGGESTED LEARNING RESOURCES

https://www.youtube.com/watch?v=WhyMOVvAu3s

8.15 SUGGESTED ASSESSMENT SCHEME

Student's Name……………………………….......……………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Accuracy in weighing of sample	15		Viva-voce	10		
Preparation of solution	15		Report preparation	10		
Housekeeping	10		Calculations, results and interpretation	10		
Use of conductivity meter	20					
Observance/ follow safety precautions	10					

2. ELECTROLYSIS OF COPPER

PRACTICAL STATEMENT

Verify the Faraday's first law of electrolysis of copper sulphate solution using copper electrode.

PRACTICAL SIGNIFICANCE

Electrolysis helps to decorate the article or machine part . It also helps to protect metal from corrosion. From Faraday's law, we can predict the amount of electricity consumed and time required for the deposition of metal or liberation of gases at particular electrode.

RELEVANT THEORY

The first law of electrolysis state that the amount of chemical change produced by current at an electrode-electrolyte boundary is proportional to the quantity of electricity used. The amount of chemical change produced by the same quantity of electricity in different substances are proportional to their equivalent weights. The weight of substance deposited or liberated at an electrode is directly proportional to the quantity of electricity passed through the electrolytes. [refer unit 5, section 5.2.3 (A) and 5.3]

PRACTICAL OUTCOMES (PrOs)

PrO1 Use resources such as rheostat, ammeter, plug key efficiently.
PrO2 Connect the circuit.
PrO3 Perform electrolysis using another metal/ electrode

PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)

For fig. refer this unit 5 section 5.3.2 2

RESOURCES, CHEMICALS AND GLASSWARE REQUIRED

- **Resources** Cu plates, iron spoon, ammeter, rheostat, plug key, battery (12 volts), connecting wires, stopwatch, polish paper, air drier, electronic balance.
- **Chemicals (AR Grade)** Copper sulphate ($CuSO_4$), 1% H_2SO_4
- **Glassware** (Borosil) Beaker (1000mL)

SAFETY PRECAUTIONS

1. Clean the iron spoon firstly with alkali then with acid, polish with polishing paper finally mount as a cathode.
2. Connect all wires properly to copper plate, iron spoon, battery etc.

SUGGESTED PROCEDURE

1. Weigh the iron spoon, before mounting the electrode as W1.
2. Setup the apparatus and connect the circuit as indicated in the figure [refer fig unit 5 section 5.3.2]
3. Adjust the required current between 1 to 2 ampere with the help of ammeter and rheostat simultaneously. Start the stopwatch.
4. Pass the current for 900 sec(15 min) using stopwatch
5. After 15 min remove iron spoon. Dry it with air drier and weigh accurately as W2

OBSERVATIONS AND CALCULATIONS

Sr. No.	Observations	Value
1	Weight of iron spoon (Cathode) before deposition (W1)	……………………g
2	Weight of iron spoon after deposition (W2)	……………………g

3	Weight of copper deposited W= W2-W1	……………………g
4	Current in ampere(actual passed)	………………….ampere
5	Time in seconds	………………….sec

Faraday's First Law of electrolysis

$W = ZIt$

$$Z = \frac{W}{It} = \frac{\dots\dots\dots\dots\dots\dots}{\dots\dots\dots\dots \times \dots\dots\dots\dots} =$$

RESULTS AND/OR INTERPRETATION

1. Electrochemical equivalent of copper =………………….g/C

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………..………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Write significance of electrolysis.
2. State law, applicable in electrolysis

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

1. Clean the glasswares thoroughly while preparing the solution. Store the prepared standard solution for further experimentation.
2. While performing this experiment, use the desired amount of substance to reduce the waste.
3. Do not waste distilled water.

SUGGESTED ASSESSMENT SCHEME

Student's Name…………………………………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Preparation of cathode	10		Viva-voce	10		
Practical setup for electrolysis	20		Report preparation	10		
Adjusting current	10		Calculation, results and interpretation	10		
Housekeeping	10					
Handling of glasswares	10					
Observance/ follow safety precautions	10					

3. MEASUREMENT OF EMF USING DANIEL CELL

PRACTICAL STATEMENT

Determine the emf using an electrochemical cell (Daniel Cell)

PRACTICAL SIGNIFICANCE

Daniel cell develops electricity from chemicals. Determination of voltage generation due to the oxidation-reduction process gives information about the transfer of electrons. It also helps to understand metal corrosion and its protection from corrosion.

RELEVANT THEORY

The potential difference between the two electrodes in a galvanic cell is called a cell potential or emf of the cell. It is measured in volts.Daniel cell is also known as a galvanic cell or voltaic cell. This cell is an example of an electrochemical cell. Generally, rods or plates are termed as electrodes. Each electrode is immersed in its metal salt solution, and these forms half-cell. Two half-cells are separated by a salt bridge or porous partition. The solution which conducts electricity either in a molten state or in an aqueous solution is called electrolytes. One electrode acts as an anode where oxidation takes place. When two metals are connected, the metal with higher activity acts as an anode while the other metal acts as the cathode.

Electrode reactions in daniel cell

Reaction at anode $Zn \longrightarrow Zn^{2+} + 2e^-$ Oxidation Reaction

Reaction at cathode $Cu^{2+} + 2e^- \longrightarrow Cu$ Reduction Reaction

$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$ Redox Reaction

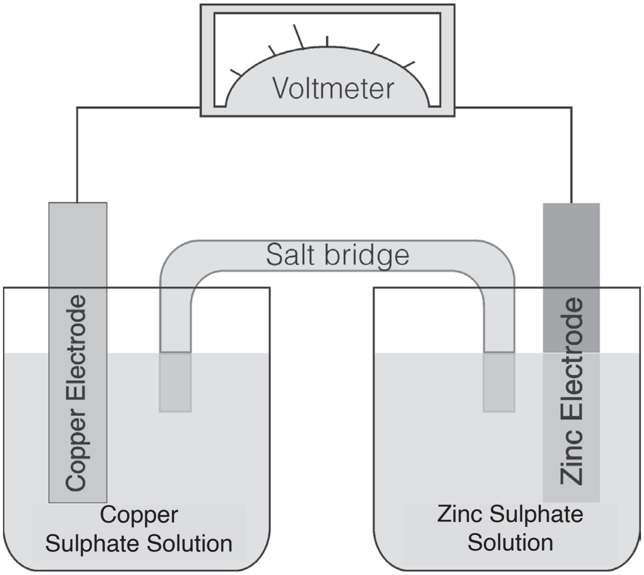
Daniel cell is represented as $Zn(s) \mid ZnSO_4\,(aq) \mid\mid CuSO_{4\,(aq)} \mid Cu(s)$

Voltage produced at daniel cell is the sum of reduction and oxidation voltage developed across the electrode is written as E^0Cell = E^0Reduction + E^0Oxidation

PRACTICAL OUTCOMES (PROS)

PrO1 Prepare complete set up for measuring emf through daniel cell.
PrO2 Use the Daniel cell for determination of emf.

PRACTICAL SETUP (DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)



A primary cell with a constant electromotive force of about 1.1 volts having as its electrodes copper in a copper sulfate solution and zinc in dilute sulfuric acid or zinc sulfate, the two solutions being separated by a porous partition. In Daniel cell Cu and Zn electrodes are immersed in $CuSO_4$ and $ZnSO_4$ solution respectively. Zn acts as anode and Cu acts as cathode. Oxidation takes place at Zn and reduction takes place at the cathode. The Zn ions passed in solution. As two electrodes are connected using an external wire, the electrons produced by oxidation of Zn move through the wire and are collected at the copper electrode. Cupric ions present in the solution (electrolyte) accept electrons and are discharged at the cathode.

RESOURCES, CHEMICALS AND GLASSWARES REQUIRED

- **Resources** Multimeter, voltmeter, connecting wires
- **Chemicals** (AR Grade) $CuSO_4$, $ZnSO_4$, Zn Rod, Cu Rod, Salt bridge
- **Glassware** (Borosil) Beaker (1000mL)

SAFETY PRECAUTIONS

1. Clean the rod by alkali, acid and finally polished by polishing paper.
2. As $CuSO_4$ is toxic to humans, care need to be taken to properly dispose it off .

SUGGESTED PROCEDURE

1. Place Zn rod in $ZnSO_4$ solution and Cu in CuSO4 solution.
2. Connect Zn rod to one end and Cu rod to another end of the multimeter.
3. Place salt bridge in both the solution. A Salt bridge is an inverted 'U' tube filled with the saturated solution of an inert electrolyte KCl/KNO_3 containing agar-agar, it releases ions into the electrolyte so that the whole solution becomes electrically neutral.

4. Take the concentration of $ZnSO_4$ and $CuSO_4$ solution as shown in observation table.
5. Prepare five different concentrations of $ZnSO_4$ and $CuSO_4$, respectively.
6. Connect two beakers with combinations shown in the observation table.
7. Record the emf developed across these two half cells.

OBSERVATIONS AND CALCULATIONS

Cell No.	Concentration of $ZnSO_4$	Concentration of $CuSO_4$	EMF produced (in Volts)
1	2Molar (M)	2M	
2	1M	2M	
3	0.5M	2M	
4	0.25M	2M	
5	0.0125M	2M	
6	2M	1M	
7	2M	0.5M	
8	2M	0.25M	
9	2M	0.0125M	

RESULTS AND/OR INTERPRETATION

1. Emf developed in cell 1 is =…………………Volts
2. Emf developed in cell 2 is =…………………Volts
3. Emf developed in cell 3 is =…………………Volts
4. Emf developed in cell 4 is =…………………Volts
5. Emf developed in cell 5 is =…………………Volts
6. Emf developed in cell 6 is =…………………Volts
7. Emf developed in cell 7 is =…………………Volts
8. Emf developed in cell 8 is =…………………Volts
9. Emf developed in cell 9 is =…………………Volts
10. Emf developed in cell 10 is =…………………Volts

CONCLUSIONS AND/OR VALIDATION

……………………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. State the function of the salt bridge in daniel cell.
2. Mention the name of anode and cathode in daniel cell.
3. Write oxidation reaction taking place at anode and cathode.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin) ♻	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.
	As $CuSO_4$ is toxic to humans, care need to be taken to properly dispose it off.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

Copper sulphate is used as a fungicide, algaecide, root killer, and herbicide in both agriculture and non-agricultural settings. As $CuSO_4$ destroys algae and bacteria, can be used appropriately. Small amount of $CuSO_4$ and $ZnSO_4$ should be taken for experimentation to avoid wastage.

SUGGESTED LEARNING RESOURCES

http://amrita.olabs.edu.in/?sub=73&brch=8&sim=153&cnt=1

Determination of EMF of a Cell

SUGGESTED ASSESSMENT SCHEME

Student's Name.. Roll No.........................

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	% Weightage	Marks Obtained	Product Indicators (30%)	% Weightage	Marks Obtained	
Preparing setup of daniel cell	20		Viva-Voce	10		
Preparation of solution	20		Report preparation	10		
Housekeeping	10		Calculations, results and interpretation	10		
Performance of experiment and observation	10					
Observance/ Follow Safety Precautions	10					

4. DISSIMILAR METAL COMBINATION

PRACTICAL STATEMENT

Determine the effect of connection of two dissimilar metals immersed in solution.

PRACTICAL SIGNIFICANCE

When two or more dissimilar metals are brought into electrical contact under water, dissimilar metal corrosion or galvanic corrosion takes place. When metal is connected to less active metal, it gets corroded, while when it is connected to more active metal, it gets protected. As diploma engineers have to work in the different situations,they should know the mechanism of corrosion.

RELEVANT THEORY

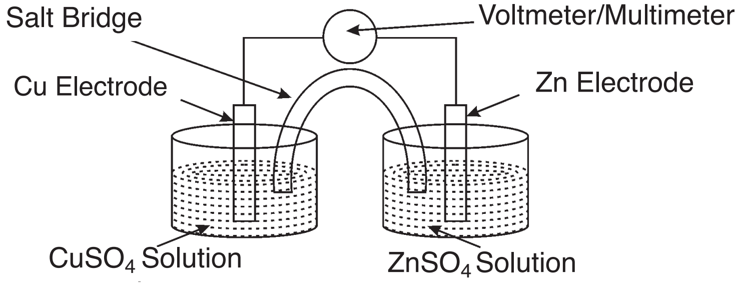
In electrochemical series , metals are arranged according to their standard electrode potential. The active metals are at the top, while less reactive or noble metals are at the bottom. Elements at a higher position in the series have a greater tendency to lose electrons. Such metals are readily oxidized. Elements at a lower position in series do not lose electrons. When two dissimilar metals are connected, the metal with a higher position in the activity series acts as anode and gets corroded, while the metal with a lower position in the activity series acts as the cathode and gets protected. When dissimilar metals contact with each other in the presence of moisture, galvanic corrosion may result. The wet metals behave like a battery and produce an electrical current. The surfaces of one or both metals become pitted and corrode, as the exchange of electrons takes place. Metal machinery can be protected by attaching a more active metal , through process called cathodic protection [Refer Unit 5 ,5.8.1].

PRACTICAL OUTCOMES (PrOs)

PrO1 : Protect the metals by using the concept of activity series .

PrO2 : Select the appropriate metal from the activity series for using it in different types of applications.

PRACTICAL SETUP
(DRAWING/SKETCH/CIRCUIT DIAGRAM/WORK SITUATION)



RESOURCES, CHEMICALS AND GLASSWARE REQUIRED

- **Resources** Voltmeter, connecting wires, electronic balance.
- **Chemical (AR Grade)** $CuSO_4$(2M), $ZnSO_4$(2M), $Al_2(SO_4)_3$(2M), Zn rod, Cu rod Al rod
- **Glasswares (Borosil)** Beaker (1000mL), Salt bridge (U tube containing KCl or KNO_3 with agar-agar)

SAFETY PRECAUTIONS

1. Clean the Zn and Cu, Al electrode with the help of alkali, acid, water and polish with polishing paper
2. Connect all wires properly
3. Clean all the glassware properly.
4. Salt bridge must be immersed in both beakers.

SUGGESTED PROCEDURE

Setup 1 (Cu-Zn cell)

1. Weigh copper and zinc rod.
2. Take zinc sulphate solution in one beaker and copper sulphate in another.
3. Immerse zinc rod as an electrode in zinc sulphate solution and copper rod as an electrode in copper sulphate solution.
4. Connect zinc rod to the negative terminal of the voltmeter and copper rod to the positive terminal of the voltmeter.
5. After 30 minutes, disconnect the cell, remove the electrodes and dry them with an air drier.
6. Weigh the zinc and copper electrodes.

Setup 2 (Zn-Al Cell)

1. Weigh aluminium and zinc rod.
2. Take zinc sulphate solution in one beaker and aluminium sulphate in another.
3. Immerse zinc rod as an electrode in zinc sulphate solution and aluminium rod as an electrode in aluminium sulphate solution.
4. Connect aluminium rod to the negative terminal of the voltmeter and zinc rod to the positive terminal of the voltmeter.
5. After 30 minutes, disconnect the cell, remove the electrodes and dry them with an air drier.
6. Weigh the zinc and aluminium electrodes.

OBSERVATIONS AND CALCULATIONS

Setup I (Cu-Zn cell)

1. Weight of copper W1 Cu before starting expriment = ……………………g
2. Weight of zinc W1 Zn before starting expriment = …………………...g

3. Weight of copper W2 Cu after 30 minutes =……………………g
4. Weight of zinc W2 Zn after 30 minutes = …………………...g
5. Change in Weight of Cu Rod =……………………g
6. Change in Weight of Zn Rod =……………………g

Setup II (Zn-Al Cell)

1. Weight of aluminium W1 Al before attachment =……………..……..g
2. Weight of zinc W1 Zn before attachment =……………..……..g
3. Weight of aluminium W2 Al after 30 minutes =……………………g
4. Weight of zinc W2 Zn after 30 minutes = ……………………g
5. Change in Weight of Al Rod =…………………...g
6. Change in Weight of Zn Rod =…………………...g

RESULTS AND/OR INTERPRETATION

1. The weight of Zn metal decreases when it is attached with ………….metal. Hence zinc get corroded when attached with…………metal.
2. The weight of Zn metal increases when it is attached with ………….metal. Hence zinc get protected when attached with…………metal.

CONCLUSIONS AND/OR VALIDATION

…..……………………………………………………………………………………………

PRACTICAL RELATED QUESTIONS

Sample questions are given here for reference, to be asked in viva-voce.

1. Write the significance of using dissimilar metals.
2. Write and explain corrosion at Zn electrode.
3. How can you prevent corrosion between dissimilar metals.

DISPOSAL OF WASTE

Types of Waste	Details
Biodegradable waste (Green bin)	Used ordinary filter paper during experimentation
Chemical Waste	Used chemicals should be appropriately disposed off, based on the properties of specific chemical used.

ENVIRONMENT FRIENDLY APPROACH: REUSE, REDUCE AND RECYCLE

- Electrodes may be reused for further experimentation.
- Metals should be preserved for further use.

SUGGESTED ASSESSMENT SCHEME

Student's Name………………………………………… Roll No……………………

Process Assessment			Product Assessment			Signature of Faculty
Process Indicators (70%)	**% Weightage**	**Marks Obtained**	**Product Indicators (30%)**	**% Weightage**	**Marks Obtained**	
Accuracy in weighing of sample	10		Viva-voce	10		
Preparation of solution	20		Report preparation	10		
Housekeeping	10		Calculations, results and interpretation	10		
Preparing setup of experiments	20					
Observance/ follow safety precautions	10					

KNOW MORE

- Basic concepts like, types of cells, conductor, insulator, polar solution, Arrhenius theory of electrolytic dissociation,degree of dissociation, electrolysis of fused NaCl, NaCl solution, $CuSO_4$ using platinum and $CuSO_4$ using copper electrode, electrochemical series, factors affecting degree of dissociation, oxidation state.
- Knowledge about series connections and parallel connections.
- The different applications of electrochemistry in daily life such as car battery, two wheeler battery, mobile battery etc. Maintenance and proper use of these should also be known.
- The effect of various factors responsible for corrosion on various metals and alloys by practically performing certain related activities, observations and analysis.

Suggested Micro projects / activities

- Collect three metallic strips of Al, Cu, Fe, Place them in different acidic and alkaline solution of same concentration. Observe and record the loss in weight of metals due to acidic and alkaline environment. Discuss the findings with your teacher and colleagues.

- Collect different samples of utensils of iron, copper, brass, bronze and other alloys. Place them in open environment under tin shade. Observe and record the corrosive properties after each second day till four weeks. Discuss the findings with your teacher and colleagues.

Inquisitiveness and Curiosity

Rusting of iron is very common and universally known phenomenon. Still, iron is widely used in construction and many industrial applications. Can our engineers, researchers and scientists explore new materials/products with similar properties for its substitute as an alternative material.

REFERENCES AND SUGGESTED READINGS

- C. N. R. Rao, Understanding Chemistry, Universities Press (India) Pvt. Ltd., 2011, ISBN 8173712506
- Dara, S. S. & Dr. S. S. Umare, Engineering Chemistry, Universities Press (India) Pvt.Ltd., 2011, ISBN, 8121903599
- Jain & Jain, Engineering Chemistry, Dhanpat Rai and Sons; New Delhi, 2015, ISBN 8187433175
- Agnihotri, Rajesh, Chemistry of Engineers, Wiley India Pvt. Ltd. 2014, ISBN 9788126550784
- Shikha Agarwal, Engineering Chemistry, Cambridge University Press; New Delhi, 2015. ISBN, 978-1-107-47641-7

APPENDIX - A

Record for Practical

S. Nos.	Page Nos.	Titles of the Experiment	Date			Marks	Signature
			Actual	Repeat	Remarks		
1	36	Prepare the standard solution of oxalic acid or potassium permanganate					
2	40	Determine the strength of given sodium hydroxide solution by titrating against standard oxalic acid solution using phenolphthalein indicator					
3	83	Estimate the total hardness of given water sample using standard ethylene diamine tetra acetic acid (EDTA) solution					
4	87	Determine the alkalinity of a given water sample using 0.01M sulphuric acid.					
5	123	Determine the percentage of iron in haematite ore by standard $KMnO_4$solution					
6	127	Estimate Iodometrically copper in the copper pyrite ore.					
7	132	Determine the Iron contents in given cement sample using colorimeter.					
8	158	Determine total acid number (TAN) of given oil					

S. Nos.	Page Nos.	Titles of the Experiment	Date			Marks	Signature
			Actual	Repeat	Remarks		
9	160	Estimate gravimetrically the moisture and ash contents in the given coal sample (Proximate Analysis).					
10	163	Determine the calorific value of solid or liquid fuel using bomb calorimeter					
11	167	Determine the viscosity of lubricating oil using Redwood viscometer					
12	171	Determine the flash and fire point of lubricating oil using Abel's flash point Apparatus					
13	202	Determine the conductivity of given water sample.					
14	205	Verify the Faraday's first law of electrolysis of copper sulphate solution using copper electrode.					
15	208	Determine the emf using an electrochemical cell (Daniel Cell)					
16	212	Determine the effect of connection of two dissimilar metals immersed in solution.					

ANNEXURE - I

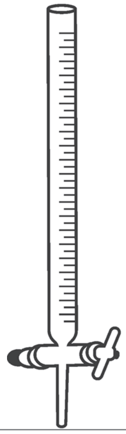
General Instructions in Chemistry Laboratory

- Students should report in the laboratory as per the time-table schedule.
- All personal belongings should be placed in the bookcases as you enter the laboratory.
- Working table should be kept clean and organized.
- First aid kit should be readily available and accessible to all.
- Each student should maintain a log book for incidental writing during instructions, performance and observation.
- Perform experimentation in the lab under the supervision of trained person.
- Laboratory personnel,students and faculty should be aware of general electrical safety guidelines/rules to be followed.
- Always follow the systematic and correct procedure of experimentation. Never take shortcuts.
- Know emergency exit routes.
- For any kind of assistance,never hesitate to ask questions with your instructor. It may be related to proper operating procedure, safety etc. Be sure that you understand every instruction before proceeding.
- Any damage to apparatus that occurs during the experimentation, should be brought to the notice of lab in-charge. You should be careful while handling the glasswares or equipment.
- Maintain proper discipline in the laboratory with utmost alertness.
- Students should come prepared with understanding of underlying concepts and principles, to perform the experiment, before coming to Laboratory.
- Record your observations as and when required
- Important emergency numbers should be displayed in the lab and known to each one
- Common safety symbols and signs should be displayed in the lab.
- Submit the lab manual/ Procedure sheets/data sheets provided to students, in time, as and when asked.
- Eating, smoking, and drinking are not allowed in the laboratory.

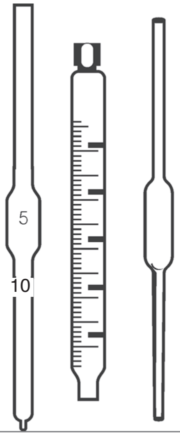
Specific Instructions in Chemistry Laboratory

- Never pour water into concentrated acid.
- Always wear proper Personal Protective Equipment (PPE) while working in the chemistry laboratory.
- Laboratory personnel,students and faculty should be well aware of operation of safety gadgets, fire extinguishers etc to avoid any accident to happen.
- All Chemicals should be properly labelled and stored appropriately.
- Laboratory personnel,students and faculty should be aware about appropriate measures to be taken in case of laboratory accidents such as chemical spills, fires and explosions, and personal injuries.
- Mouth suction is never used to fill a pipette
- Laboratory personnel,students and faculty should be aware about proper disposal of chemical wastes, storing specific chemicals, use of safety and emergency equipment, assessing chemical hazards
- Laboratory personnel,students and faculty should be well aware about appropriate measures to be taken in case of chemical burns,heat burns,eye injuries,cuts from glassware,inhaling dangerous gases etc .
- Make sure that all flammable reagents are well removed before lighting the burner
- Before leaving the laboratory, make sure that your work area is clean and dry. Ensure that all gas, water, vacuum, and air valves are completely turned off.
- Use the fume hoods when toxic or irritating vapours are evolved.
- When the experiment is completed, students should clean the apparatus and glasswares. Carefully dispose off the leftover chemicals. Disconnect the setup made by them and should return all the components/ instruments taken for the purpose.
- Never place chemicals directly on the balance pan. Always use a proper weighing container when using a balance to weigh a chemical.
- Wash your hands thoroughly after leaving the laboratory.
- Keep the reagents in their proper places after use. Do not alter their position.
- Do not pour concentrated acids into the sink. Do not throw any waste paper / litmus paper etc. into the sink. Throw them into the dustbin. Keep gas taps and water taps closed when not in use.
- The common laboratory glasswares used in chemistry laboratory are given below.

Common Laboratory Glasswares

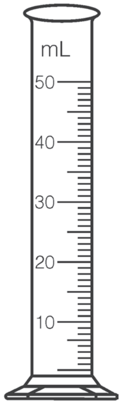


Burette



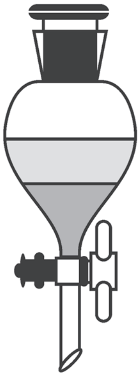
Pipette

Test - Tube

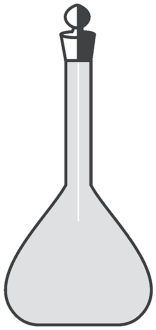


Measuring Cylinder

Conical Flask



Separating Funnel



Volumetric Flask

Beaker

Filter Funnel

REFERENCES FOR FURTHER LEARNING

Books :

- C. N. R. Rao, Understanding Chemistry, Universities Press (India) Pvt. Ltd., 2011, ISBN 8173712506

- Dara, S. S. & Dr. S. S. Umare, Engineering Chemistry, Universities Press (India) Pvt. Ltd., 2011, ISBN, 8121903599

- Jain & Jain, Engineering Chemistry, Dhanpat Rai and Sons; New Delhi, 2015, ISBN 8187433175

- Agnihotrri, Rajesh, Chemistry of Engineers, Wiley India Pvt. Ltd. 2014, ISBN 9788126550784

- Dr. G. H. Hugar & Prof. A. N. Pathak, Applied Chemistry Laboratory Practices, Vol.I and Vol.II, NITTTR, Chandigarh, Publications, 2013 - 14.
- Shikha Agarwal, Engineering Chemistry, Cambridge University Press; New Delhi, 2015. ISBN, 978-1-107-47641-7

- Dr. Vairam S., Engineering Chemistry, Wiley India Pvt.Ltd., New Delhi, 2013, 43035

- Text Book of Chemistry for Class XI & XII (Part - I, Part - II), N.C.E.R.T., Delhi, 2017-18.

- Dr. B. S. Chouhan, Engineering Chemistry, Laxmi Publications, 97893 - 81159514

Open Source Software and Website Address:

- www.chemguide.co.uk/atommenu.html (Atomic Structure and Chemical Bonding)
- www.visionlearning.com (Atomic Structure and Chemical Bonding
- www.chem1.com (Atomic Structure and Chemical Bonding)
- https://www.wastewaterelearning.com/elearning/ (Water Treatment)
- www.capital-refractories.com (Metals, Alloys, Cement, and Refractory Materials)
- www.em-ea.org/guide%20books/book-2/2.1%20fuels%20and%20combustion.pdf (Fuel and Combustion)
- www.chemcollective.org (Metals, Alloys)
- www.wqa.org(Water Treatment)

CO AND PO ATTAINMENT TABLE

Course Outcomes	Mapping with Programme Outcomes (1-Weak Correlation; 2-Medium Correlation; 3-Strong Correlation)						
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7
CO-1							
CO-2							
CO-3							
CO-4							
CO-5							

INDEX