GOVERNMENT OF TAMILNADU

STANDARD TEN

SCIENCE

A Publication under Free Textbook Programme of Government of Tamil Nadu

Department of School Education

Untouchability is Inhuman and a Crime

Government of Tamil Nadu

First Edition - 2019

(Published under New syllabus)

Content Creation

State Council of Educational
Research and Training

Printing & Publishing

Tamil NaduTextbook and
Educational Services Corporation

www.textbooksonline.tn.nic.in

PREFACE

This book is developed in a holistic approach which inculcates comprehending and analytical skills. It will be helpfull for the students to understand higher secondary science in a better way and to prepare for competitive exams in future. This textbook is designed in a learner centric way to trigger the thought process of students through activities and to make them excel in learning science.

HOW TO USE THE BOOK

- This book has 23 units.
- Each unit has simple activities that can be demonstrated by the teacher and also few group activities are given for students to do under the guidance of the teacher.
- Infographics and info-bits are added to enrich the learner's scientific perception.
- The "Do you know?" and "More to know" placed in the units will be an eye opener.
- Glossary has been introduced to learn scientific terms.
- ICT corner and QR code are introduced in each unit for the digital native generation.

How to get connected to QR Code?

QR GUIDE

- Download the QR code scanner from the google play store/
apple app store into your smartphone
- Open the QR code scanner application
- Once the scanner button in the application is clicked, camera opens and then bring it closer to the QR code in the textbook.
- Once the camera detects the QR code, a URL appears in the screen. Click the URL and go to the content page.

Career Guidance

Engineering Courses B.E. / B.Tech
4 years

- Aeronautical Engineering
- Aerospace Engineering
- Architecture Engineering
- Automobile Engineering
- Automation & Robotics Engineering
- Avionics Engineering
- Bio Medical Engineering
- Bio Technology Engineering
- Civil Engineering
- Chemical Engineering
- Ceramic Engineering
- Computer Science Engineering
  Construction Management &
  Technology Engineering
- Electronics and Communication Engineering
- Electrical and Electronics Engineering
- Environmental Science Engineering
- Information Science Engineering
- Industrial Engineering
- Industrial Production Engineering
- Instrumentation Technology
- Marine Engineering
- Medical Electronics Engineering
- Mechanical Engineering
- Mining Engineering
- Manufacturing Science Engineering
- Naval Architecture
- Polymer Technology
- Silk Technology Engineering
- Carpet Technology Engineering
- Textile Engineering

Medical Course
5 years

- MBBS – Allopathy
- BSMS – Siddha
- BAMS - Ayurveda
- BUMS – Unani
- BHMS – Homeopathy
- BNYS – Naturopathy & Yoga
- BDS – Dental
- BVSc – Veterinary

Agriculture Courses|
(4 years)

- B.Sc. Agriculture Science
- B.Sc. Horticulture
- B.Sc. Forestry
- B.Tech Agricultural Engineering

Paramedical Diploma / UG
2/3 years

- Nursing
- Pharmacy
- Anaesthesia Technician
- Cardiac Technician
- Dental Mechanic
- Health Inspector
- Medical imaging & tech
- Medical Lab Tech
- Medical X-ray Tech
- Nuclear Medicine Tech
- Occupational therapist
- Operation Theatre Tech
- Ophthalmic Assistant
- Physiotherapy
- Radiographic Assistant
- Radiotherapy Tech
- Rehabilitation Tech
- Respiratory Therapy Tech
- Blood Transfusion Tech

Humanities
3 years

- Advertising
- BA-General Criminology
- Economics
- Fine Arts
- Foreign Languages
- Home Science
- Interior Design
- Journalism
- Library Sciences
- Physical Education
- Political Science
- Psychology
- Social Work
- Sociology
- Travel & Tourism

Road ahead after 12^{th}...

B.Sc., Courses
3 years

- B.Sc. Physics
- B.Sc. Chemistry
- B.Sc. Botany
- B.Sc. Zoology
- B.Sc. Mathematics
- B.Sc. Computer Science
- B.Sc. PCM
- B.Sc. CBZ
- B.Sc. Dietician & Nutritionist
- B.Sc. Sericulture
- B.Sc. Oceanography
- B.Sc. Meteorology
- B.Sc. Anthropology
- B.Sc. Forensic Sciences
- B.Sc. Food Technology
- B.Sc. Dairy Technology
- B.Sc. Hotel Management
- B.Sc. Fashion Design
- B.Sc. Mass Communication
- B.Sc. Electronic Media
- B.Sc. Multimedia
- B.Sc. 3D Animation
- B.Sc. Home Science

PLAN

Commerce Courses
3 years

- CA – Chartered Accountant
- CMA Cost Management Accountant
- CS Company Secretary (Foundation)
- B.com – Regular
- B.com – Taxation & Tax Procedure
- B.com – Travel & Tourism
- B.com – Bank Management
- B.com – Professional
- BBA/BBM – Regular
- BFM – Bachelors in Financial Markets
- BMS – Bachelors in Management Studies
- BAF – Bachelors in Accounting & Finance
- Certified Stock Broker & Investment Analysis
- Certified Financial Analyst
- Certified Financial Planner
- Certified Investment Banker

Management Courses
(3 years)

- Business Management
- Bank Management
- Event Management
- Hospital Management
- Hotel Management
- Human Resources Management
- Logistics & Management

Law Courses
3.5 years

- LLB
- BA+LLB
- B.Com + LLB
- BBM+LLB
- BBA+LLB

C.A

CPT
↓
ATC IPCC
↓
ITT
(100 Hours)
↓
Articleship
(Work under in CA)
↓
Clear Final Exam
Become a C.A.

JOB / Post Graduation

STANDARD TEN

SCIENCE

Table of Contents

2JXFAF

E - book

2K7BC3

Assessment

B375_10_SCIENCE_EM

DIGI links

LAWS OF MOTION

Learning Objectives

2ZGABR

At the end of this lesson students will be able to:

- Understand the concepts of force and motion.
- Explain inertia and its types.
- State the three laws of Newton.
- Apply Newtonian concept of force and motion.
- Define force, momentum and impulse.
- Distinguish between mass and weight
- Analyze weightlessness and the principle of conservation of momentum.
- Explain the law of gravitation and its applications.
- Understand the variations in 'g' due to height and depth.
- Solve numerical problems related to force and motion

INTRODUCTION

Human beings are so curious about things around them. Things around us are related to one another. Some bodies are at rest and some are in motion. Rest and motion are interrelated terms.

In the previous classes you have learnt about various types of motion such as linear motion, circular motion, oscillatory motion, and so on. So far, you have discussed the motion of bodies in terms of their displacement, velocity, and acceleration. In this unit, let us investigate the cause of motion.

When a body is at rest, starts moving, a question that arises in our mind is 'what causes the body to move?' Similarly, when a moving object comes to rest, you would like to know what brings it to rest? If a moving object speeds up or slows down or changes its direction. what speeds up or slows down the body? What changes the direction of motion?

One answer for all the above questions is 'Force'. In a common man's understanding of motion, a body needs a 'push' or 'pull' to move, or bring to rest or change its velocity. Hence, this 'push' or 'pull' is called as 'force'.

Let us define force in a more scientific manner using the three laws proposed by Sir Isaac Newton. These laws help you to understand the motion of a body and also to predict the future course of its motion, if you know the forces acting on it. Before Newton formulated his three laws of motion, a different perception about the force and motion of bodies prevailed. Let us first look at these ideas and then eventually learn about Newton's laws in this unit.

Mechanics is the branch of physics that deals with the effect of force on bodies. It is divided into two branches, namely, statics and dynamics.

Statics: It deals with the bodies, which are at rest under the action of forces.

Dynamics: It is the study of moving bodies under the action of forces. Dynamics is further divided as follows.

Kinematics: It deals with the motion of bodies without considering the cause of motion.

Kinetics: It deals with the motion of bodies considering the cause of motion.

1.1 FORCE AND MOTION

According to *Aristotle* a Greek Philosopher and Scientist, the natural state of earthly bodies is 'rest'. He stated that a moving body naturally comes to rest without any external influence of the force. Such motions are termed as **'natural motion' (Force independent).** He also proposed that a force (a push or a pull) is needed to make the bodies to move from their natural state (rest) and behave contrary to their own natural state called as **'violent motion' (Force dependent)**. Further, he said, when two differnt mass bodies are dropped from a height, the heavier body falls faster than the lighter one.

Galileo proposed the following concepts about force, motion and inertia of bodies:

(i) The natural state of all earthly bodies is either the state of rest or the state of uniform motion.

(ii) A body in motion will continue to be in the same state of motion as long as no external force is applied.

(iii) When a force is applied on bodies, they resist any change in their state. This property of bodies is called 'inertia'.

(iv) When dropped from a height in vacuum, bodies of different size, shape and mass fall at the same rate and reach the ground at the same time.

1.2 INERTIA

While you are travelling in a bus or in a car, when a sudden brake is applied, the upper part of your body leans in the forward direction. Similarly, when the vehicle suddenly is move forward from rest, you lean backward. This is due to, any body would like to continue to be in its state of rest or the state of motion. This is known as 'inertia'.

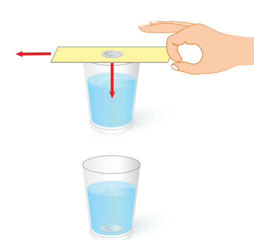
The inherent property of a body to resist any change in its state of rest or the state of uniform motion, unless it is influenced upon by an external unbalanced force, is known as **'inertia'.**

Activity 1

Take a glass tumbler and place a small cardboard on it as shown in the figure. Now, keep a coin at the centre of the cardboard. Then, flick the cardboard quickly. What do you observe?

The cardboard falls off the ground and the coin falls into the glass tumbler.

Inertia of rest



In activity described above, the inertia of the coin keeps it in the state of rest when the cardboard moves. Then, when the cardboard has moved, the coin falls into the tumbler due to gravity. This happen due to 'inertia of rest'.

1.2.1 Types of Inertia

a) **Inertia of rest:** The resistance of a body to change its state of rest is called inertia of rest.

b) **Inertia of motion**: The resistance of a body to

3EZ5D3

change its state of motion is called inertia of motion.

c) **Inertia of direction:** The resistance of a body to change its direction of motion is called inertia of direction.

1.2.2 Examples of Inertia

- An athlete runs some distance before jumping. Because, this will help him jump longer and higher. (Inertia of motion)
- When you make a sharp turn while driving a car, you tend to lean sideways, (Inertia of direction).
- When you vigorously shake the branches of a tree, some of the leaves and fruits are detached and they fall down, (Inertia of rest).

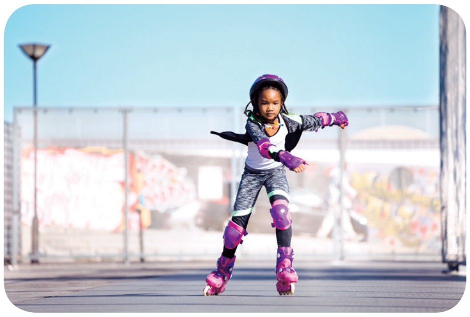


Figure 1.1 Inertia of motion

1.3 LINEAR MOMENTUM

The impact of a force is more if the velocity and the mass of the body is more. To quantify the impact of a force exactly, a new physical quantity known as linear momentum is defined. The linear momentum measures the impact of a force on a body.

The product of mass and velocity of a moving body gives the magnitude of linear momentum. It acts in the direction of the velocity of the object. Linear momentum is a vector quantity.

Linear Momentum = mass × velocity

$$p = m\,v \quad \text{..........(1.1)}$$

It helps to measure the magnitude of a force. Unit of momentum in SI system is kg m s^{-1} and in C.G.S system its unit is g cm s^{-1}.

1.4 NEWTON'S LAWS OF MOTION

1.4.1 Newton's First Law

This law states that **every body continues to be in its state of rest or the state of uniform motion along a straight line unless it is acted upon by some external force.** It gives the definition of force as well as inertia.

1.4.2 Force

Force is an external effort in the form of push or pull, which:

1. produces or tries to produce the motion of a static body.
2. stops or tries to stop a moving body.
3. changes or tries to change the direction of motion of a moving body.

Force has both magnitude and direction. So, it is a vector quantity.

1.4.3 Types of forces

Based on the direction in which the forces act, they can be classified into two types as: (a) Like parallel forces and (b) Unlike parallel forces.

(a) **Like parallel forces:** Two or more forces of equal or unequal magnitude acting along the same direction, parallel to each other are called like parallel forces.

(b) **Unlike parallel forces:** If two or more equal forces or unequal forces act along opposite directions parallel to each other, then they are called unlike parallel forces. Action of forces are given in Table 1.1.

1.4.4 Resultant Force

When several forces act simultaneously on the same body, then the combined effect of the multiple forces can be represented by a single force, which is termed as '*resultant force*'. It is equal to the vector sum (adding the magnitude of the forces with their direction) of all the forces.

Table 1.1 Action of forces

Action of forces	Diagram	Resultant force (F_{net})
Parallel forces are acting in the same direction	F_1 F_2	$F_{net} = F_1 + F_2$
Parallel unequal forces are acting in opposite directions	F_1 F_2	$F_{net} = F_1 - F_2$ (if $F_1 > F_2$) $F_{net} = F_2 - F_1$ (if $F_2 > F_1$) F_{net} is directed along the greater force.
Parallel equal forces are acting in opposite directions in the same line of action ($F_1 = F_2$)	F_1 F_2	$F_{net} = F_1 - F_2$ ($F_1 = F_2$) $F_{net} = 0$

(a) Unlike parallel forces – Tug of war

(b) Unbalanced forces - Action of a lever

(c) Like parallel forces

Figure 1.2 Combined effect of forces

If the resultant force of all the forces acting on a body is equal to zero, then the body will be in equilibrium. Such forces are called **balanced forces**. If the resultant force is not equal to zero, then it causes the motion of the body due to **unbalanced forces**

Examples: Drawing water from a well, force applied with a crow bar, forces on a weight balance, etc.

A system can be brought to equilibrium by applying another force, which is equal to the resultant force in magnitude, but opposite in direction. Such force is called as '**Equilibrant**'.

1.4.5 Rotating Effect of Force

Have you observed the position of the handle in a door? It is always placed at the edge of door and not at some other place. Why? Have you tried to push a door by placing your hand closer to the hinges or the fixed edge? What do you observe?

The door can be easily opened or closed when you apply the force at a point far away from the fixed edge. In this case, the effect of the force you apply is to turn the door about the fixed edge. This turning effect of the applied force is more when the distance between the fixed edge and the point of application of force is more.

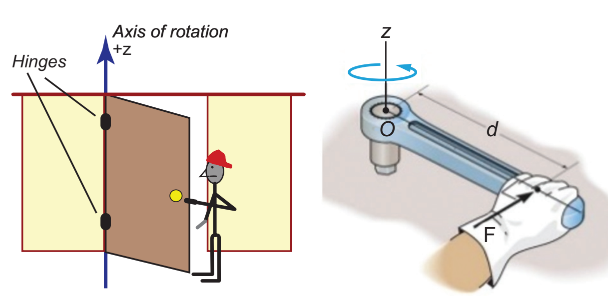


Figure 1.3 Rotating effect of a force

The axis of the fixed edge about which the door is rotated is called as '*axis of rotation*'. Fix one end of a rod to the floor/wall, and apply a force at the other end tangentially.

The rod will be turned about the fixed point is called as '*point of rotation*'.

1.4.6 Moment of the Force

The rotating or turning effect of a force about a fixed point or fixed axis is called **moment of the force** about that point or **torque (τ)**. It is measured by the product of the force (F) and the perpendicular distance (d) between the fixed point or the fixed axis and the line of action of the force.

$$\tau = F \times d \quad \ldots\ldots\ldots\ldots (1.2)$$

Torque is a vector quantity. It is acting along the direction, perpendicular to the plane containing the line of action of force and the distance. Its SI unit is N m.

Couple: Two equal and unlike parallel forces applied simultaneously at two distinct points constitute a couple. The line of action of the two forces does not coincide. It does not produce any translatory motion since the resultant is zero. But, a couple results in causes the rotation of the body. Rotating effect of a couple is known as **moment of a couple**.

Examples: Turning a tap, winding or unwinding a screw, spinning of a top, etc.

Moment of a couple is measured by the product of any one of the forces and the perpendicular distance between the line of action of two forces. The turning effect of a couple is measured by the magnitude of its moment.

Moment of a couple = Force × perpendicular distance between the line of action of forces

$$M = F \times S \quad \ldots\ldots\ldots\ldots (1.3)$$

The unit of moment of a couple is newton metre (N m) in SI system and dyne cm in CGS system.

By convention, the direction of moment of a force or couple is taken as positive if the body is rotated in the anti-clockwise direction and negative if it is rotate in the clockwise direction. They are shown in Figures 1.4 (a and b)

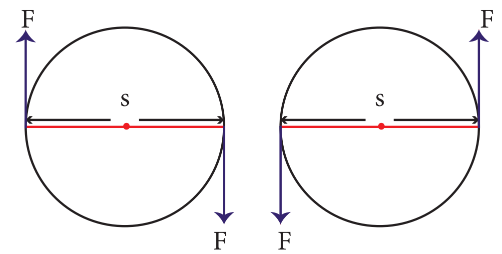


Figure 1.4 (a) Clockwise moment   **Figure 1.4 (b)** Anticlockwise moment

1.4.7 Application of Torque

1. Gears:

A gear is a circular wheel with teeth around its rim. It helps to change the speed of rotation of a wheel by changing the torque and helps to transmit power.

2. Seasaw

Most of you have played on the seasaw. Since there is a difference in the weight of the persons sitting on it, the heavier person lifts the lighter person. When the heavier person comes closer to the pivot point (fulcrum) the distance of the line of action of the force decreases. It causes less amount of torque to act on it. This enables the lighter person to lift the heavier person.

3. Steering Wheel

A small steering wheel enables you to manoeuore a car easily by transferring a torque to the wheels with less effort.

1.4.8 Principle of Moments

When a number of like or unlike parallel forces act on a rigid body and the body is in equilibrium, then the algebraic sum of the moments in the clockwise direction is equal to the algebraic sum of the moments in the anticlockwise direction. In other words, at equilibrium, the algebraic sum of the moments of all the individual forces about any point is equal to zero.

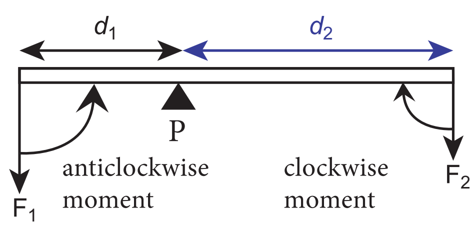


Figure 1.5 Principle of moments

In the illustration given in figure 1.5, the force F_1 produces an anticlockwise rotation at a distance d_1 from the point of pivot P (called fulcrum) and the force F_2 produces a clockwise rotation at a distance d_2 from the point of pivot P. The principle of moments can be written as follows:

Moment in clockwise direction = Moment in anticlockwise direction

$$F_1 \times d_1 = F_2 \times d_2 \quad \ldots\ldots\ldots \quad (1.4)$$

1.5 NEWTON'S SECOND LAW OF MOTION

According to this law, "**the force acting on a body is directly proportional to the rate of change of linear momentum of the body and the change in momentum takes place in the direction of the force**".

This law helps us to measure the amount of force. So, it is also called as '*law of force*'. Let, 'm' be the mass of a moving body, moving along a straight line with an initial speed 'u' After a time interval of 't', the velocity of the body changes to 'v' due to the impact of an unbalanced external force F.

Initial momentum of the body $P_i = mu$

Final momentum of the body $P_f = mv$

Change in momentum $\Delta p = P_f - P_i = mv - mu$

By Newton's second law of motion,

Force, F $\propto$ rate of change of momentum

F $\propto$ change in momentum / time

$$F \propto \frac{mv - mu}{t}$$

$$F = \frac{km(v-u)}{t}$$

Here, k is the proportionality constant. k = 1 in all systems of units. Hence,

$$\mathbf{F = \frac{m(v-u)}{t}} \qquad (1.5)$$

Since, acceleration = change in velocity/ time, a=(v-u)/t. Hence, we have

$$\mathbf{F = m \times a} \qquad (1.6)$$

Force = mass × acceleration

No external force is required to maintain the motion of a body moving with uniform velocity. When the net force acting on a body is not equal to zero, then definitely the velocity of the body will change. Thus, change in momentum takes place in the direction of the force. The change may take place either in magnitude or in direction or in both.

Force is required to produce the acceleration of a body. In a uniform circular motion, even though the speed (magnitude of velocity) remains constant, the direction of the velocity changes at every point on the circular path. So, the acceleration is produced along the radius called as *centripetal acceleration*. The force, which produces this acceleration is called as centripetal force, about which you have learnt in class IX.

Units of force: SI unit of force is newton (N) and in C.G.S system its unit is dyne.

Definition of 1 newton (N): The amount of force required for a body of mass 1 kg produces an acceleration of 1 m s^{-2}, **1 N = 1 kg m s^{-2}**

Definition of 1 dyne: The amount of force required for a body of mass 1 gram produces an acceleration of 1 cm s^{-2}, **1 dyne = 1 g cm s^{-2}**; also **1 N = 10^5 dyne.**

Unit force:

The amount of force required to produce an acceleration of 1 m s^{-2} in a body of mass 1 kg is called '*unit force*'.

Gravitational unit of force:

In the SI system of units, gravitational unit of force is kilogram force, represented by kg f. In the CGS system its unit is gram force, represented by g f.

1 kg f = 1 kg × 9.8 m s^{-2} = 9.8 N;

1 g f = 1 g × 980 cm s^{-2} = 980 dyne

1.6 Impulse

A large force acting for a very short interval of time is called as '**Impulsive force**'. When a force F acts on a body for a period of time t, then the product of force and time is known as '**impulse**' represented by 'J'

Impulse, $J = F \times t$ (1.7)

By Newton's second law

$F = \Delta p / t$ (Δ refers to change)

$\Delta p = F \times t$ (1.8)

From 1.7 and 1.8

$$\mathbf{J = \Delta p}$$

Impulse is also equal to the magnitude of change in momentum. Its unit is kg m s^{-1} or N s.

Change in momentum can be achieved in two ways. They are:

i. a large force acting for a short period of time and

ii. a smaller force acting for a longer period of time.

Examples:

- Automobiles are fitted with springs and shock absorbers to reduce jerks while moving on uneven roads.
- In cricket, a fielder pulls back his hands while catching the ball. He experiences a smaller force for a longer interval of time to catch the ball, resulting in a lesser impulse on his hands.

Figure 1.6 Example of impulsive force

1.7 NEWTON'S THIRD LAW OF MOTION

Newton's third law states that '**for every action, there is an equal and opposite reaction. They always act on two different bodies**'.

If a body A applies a force F_A on a body B, then the body B reacts with force F_B on the body A, which is equal to F_A in magnitude, but opposite in direction. $F_B = -F_A$

Examples:

- When birds fly they push the air downwards with their wings (Action) and the air pushes the bird upwards (Reaction).
- When a person swims he pushes the water using the hands backwards (Action), and the water pushes the swimmer in the forward direction (Reaction).
- When you fire a bullet, the gun recoils backward and the bullet is moving forward (Action) and the gun equalises this forward action by moving backward (Reaction).

1.8 PRINCIPLE OF CONSERVATION OF LINEAR MOMENTUM

There is no change in the linear momentum of a system of bodies as long as no net external force acts on them.

3UHZEE

Let us prove the law of conservation of linear momentum with the following illustration:

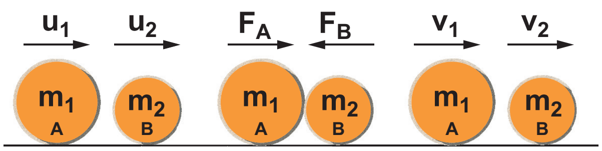


Figure 1.7 Conservation of linear momentum

Proof:

Let two bodies A and B having masses m_1 and m_2 move with initial velocity u_1 and u_2 in a straight line. Let the velocity of the first body be higher than that of the second body. i.e., $u_1>u_2$. During an interval of time t second, they tend to have a collision. After the impact, both of them move along the same straight line with a velocity v_1 and v_2 respectively.

Force on body B due to A,

$$F_B = m_2 (v_2-u_2)/t$$

Force on body A due to B,

$$F_A = m_1 (v_1-u_1)/t$$

By Newton's III law of motion,

Action force = Reaction force

$$F_A = -F_B$$

$$m_1 (v_1-u_1)/t = -m_2 (v_2-u_2)/t$$

$$\mathbf{m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2} \text{ ------ } \mathbf{(1.9)}$$

The above equation confirms **in the absence of an external force, the algebraic sum of the momentum after collision is numerically equal to the algebraic sum of the momentum before collision.**

Hence the law of conservation linear momentum is proved.

1.9 ROCKET PROPULSION

Propulsion of rockets is based on the law of conservation of linear momentum as well as Newton's III law of motion. Rockets are filled with a fuel (either liquid or solid) in the propellant tank. When the rocket is fired, this fuel is burnt and a hot gas is ejected with a high speed from the nozzle of the rocket, producing a huge momentum. To balance this momentum, an equal and opposite reaction force is produced in the combustion chamber, which makes the rocket project forward.

While in motion, the mass of the rocket gradually decreases, until the fuel is completely burnt out. Since, there is no net external force acting on it, the linear momentum of the system is conserved. The mass of the rocket decreases with altitude, which results in the gradual increase in velocity of the rocket. At one stage, it reaches a velocity, which is sufficient to just escape from the gravitational pull of the Earth. This velocity is called *escape velocity*. (This topic will be discussed in detail in higher classes).

1.10 GRAVITATION

1.10.1 Newton's universal law of gravitation

This law states that **every particle of matter in this universe attracts every other particle with a force. This force is directly proportional to the product of their masses and inversely proportional to the square of the distance between the centers of these masses. The direction of the force acts along the line joining the masses**.

Force between the masses is always attractive and it does not depend on the medium where they are placed.

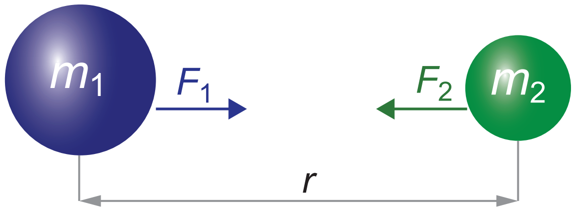


Figure 1.8 Gravitational force between two masses

Let, m_1 and m_2 be the masses of two bodies A and B placed *r* metre apart in space

Force $F \propto m_1 \times m_2$

$F \propto 1/r^2$

On combining the above two expressions

$$F \propto \frac{m_1 \times m_2}{r^2}$$

$$\mathbf{F = \frac{G\, m_1\, m_2}{r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.10)$$

Where G is the universal gravitational constant. Its value in SI unit is 6.674×10^{-11} N $m^2\, kg^{-2}$.

1.10.2 Acceleration due to gravity (g)

When you throw any object upwards, its velocity ceases at a particular height and then it falls down due to the gravitational force of the Earth.

The velocity of the object keeps changing as it falls down. This change in velocity must be due to the force acting on the object. The acceleration of the body is due to the Earth's gravitational force. So, it is called as 'acceleration due to the gravitational force of the Earth' or **'acceleration due to gravity of the Earth'**. It is represented as 'g'. Its unit is m s^{-2}

Mean value of the acceleration due to gravity is taken as 9.8 m s^{-2} on the surface of the Earth. This means that the velocity of a body during the downward free fall motion varies by 9.8 m s^{-1} for every 1 second. However, the value of 'g' is not the same at all points on the surface of the earth.

1.10.3 Relation between g and G

When a body is at rests on the surface of the Earth, it is acted upon by the gravitational force of the Earth. Let us compute the magnitude of this force in two ways. Let, M be the mass of the Earth and m be the mass of the body. The entire mass of the Earth is assumed to be concentrated at its centre. The radius of the Earth is R = 6378 km (= 6400 km approximately). By Newton's law of gravitation, the force acting on the body is given by

$$F = \frac{G\,M\,m}{R^2} \qquad (1.11)$$

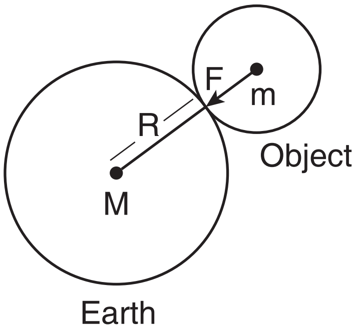


Figure 1.9 Relation between g and G

Here, the radius of the body considered is negligible when compared with the Earth's radius. Now, the same force can be obtained from Newton's second law of motion. According to this law, the force acting on the body is given by the product of its mass and acceleration (called as weight). Here, acceleration of the body is under the action of gravity hence a = g

F = m a = m g

F = weight = mg ------------------- (1.12)

Comparing equations (1.7) and (1.8), we get

$$\mathbf{mg = \frac{GMm}{R^2}} \quad \text{-----------------------} \quad (1.13)$$

Acceleration due to gravity

$$\mathbf{g = \frac{GM}{R^2}} \quad \text{------------------------------} \quad (1.14)$$

1.10.4 Mass of the Earth (M)

Rearranging the equation (1.14), the mass of the Earth is obtained as follows:

Mass of the Earth $M = g\,R^2/G$

Substituting the known values of g, R and G, you can calculate the mass of the Earth as

$\mathbf{M = 5.972 \times 10^{24}\ kg}$

1.10.5 Variation of acceleration due to gravity (g):

Since, g depends on the geometric radius of the Earth, ($g \propto 1/R^2$), its value changes from one place to another on the surface of the Earth. Since, the geometric radius of the Earth is maximum in the equatorial region and minimum in the polar region, the value of g is maximum in the polar region and minimum at the equatorial region.

When you move to a higher altitude from the surface of the Earth, the value of g reduces. In the same way, when you move deep below the surface of the Earth, the value of g reduces. (This topic will be discussed in detail in the higher classes). Value of g is zero at the centre of the Earth.

1.11 MASS AND WEIGHT

Mass: Mass is the basic property of a body. Mass of a body is defined as the quantity of matter contained in the body. Its SI unit is kilogram (kg).

Weight: Weight of a body is defined as the gravitational force exerted on it due to the Earth's gravity alone.

Weight = Gravitational Force

= mass (m)× acceleration due to gravity(g).

g = acceleration due to gravity for Earth (at sea level) = 9.8 m s^{-2}.

Weight is a vector quantity. Direction of weight is always towards the centre of the Earth. SI unit of weight is newton (N). Weight of a body varies from one place to another place on the Earth since it depends on the acceleration due to gravity of the Earth (g) weight of a body is more at the poles than at the equatorial region.

The value of acceleration due to gravity on the surface of the moon is 1.625 ms^{-2}. This is about 0.1654 times the acceleration due to gravity of the Earth. If a person whose mass is 60 kg stands on the surface of Earth, his weight would be 588 N ($W = mg = 60 \times 9.8$). If the same person goes to the surface of the Moon, he would weigh only 97.5 N ($W = 60 \times 1.625$). But, his mass remains the same (60 kg) on both the Earth and the Moon.

1.12 APPARENT WEIGHT

The weight that you feel to possess during up and down motion, is not same as your actual weight. Apparent weight is the weight of the body acquired due to the action of gravity and other external forces acting on the body.

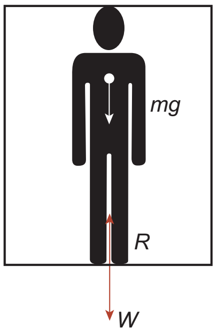


Figure 1.10
A person in a moving lift

Let us see this from the following illustration:

Let us consider a person of mass m, who is travelling in lift. The actual weight of the person is W = mg, which is acting vertically downwards. **The reaction force exerted by the lift's surface 'R', taken as apparent weight** is acting vertically upwards.

Let us see different possibilities of the apparent weight 'R' of the person that arise, depending on the motion of the lift; upwards or downwards which are given in Table 1.2

1.12.1 Weightlessness

Have you gone to an amusement park and taken a ride in a roller coaster? or in a giant wheel? During the fast downward and upward movement, how did you feel?

4PATFE

Table 1.2 Apparent weight of a person in a moving lift

Case 1: Lift is moving **upward** with an acceleration 'a'	Case 2: Lift is moving **downward** with an acceleration 'a'	Case 3: Lift is at **rest**.	Case 4: Lift is **falling down freely**
$R - W = F_{net} = ma$ $R = W + ma$ $R = mg + ma$ $\mathbf{R = m(g+a)}$	$W - R = F_{net} = ma$ $R = W - ma$ $R = mg - ma$ $\mathbf{R = m(g-a)}$	Here, the acceleration is zero $a = 0$ $R = W$ $\mathbf{R = mg}$	Here, the acceleration is equal to g $a = g$ $\mathbf{R = m(g-g)}$
$R > W$	$R < W$	$R = W$	$R = 0$
Apparent weight is **greater** than the actual weight.	Apparent weight is **lesser** than the actual weight.	Apparent weight is **equal** to the actual weight.	Apparent weight is equal to **zero**.

Figure 1.11 Weightlessness in a roller coaster

Its amazing!!. You actually feel as if you are falling freely without having any weight. This is due to the phenomenon of 'weightlessness'. You seem to have lost your weight when you move down with a certain acceleration. Sometimes, you experience the same feeling while travelling in a lift.

When the person in a lift moves down with an acceleration (a) equal to the acceleration due to gravity (g), i.e., when $a = g$, this motion is called as '*free fall*'. Here, the apparent weight ($R = m(g-g) = 0$) of the person is zero. This condition or state refers to the state of weightlessness. (Refer case 4 from Table 1.2).

The same effect takes place while falling freely in a roller coaster or on a swing or in a vertical giant wheel. You feel an apparent weight loss and weight gain when you are moving up and down in such rides.

1.12.2 Weightlessness of the astronauts

Some of us believe that the astronauts in the orbiting spacestation do not experience any gravitational force of the Earth. So they float. But this is absolutely wrong.

Astronauts are not floating but falling freely around the earth due to their huge oribital velocity. Since spacestation and astronauts have equal acceleration, they are under free fall condition. ($R = 0$ refer case 4 in Table 1.2). Hence, both the astronauts and the spacestation are in the state of weightlessness.

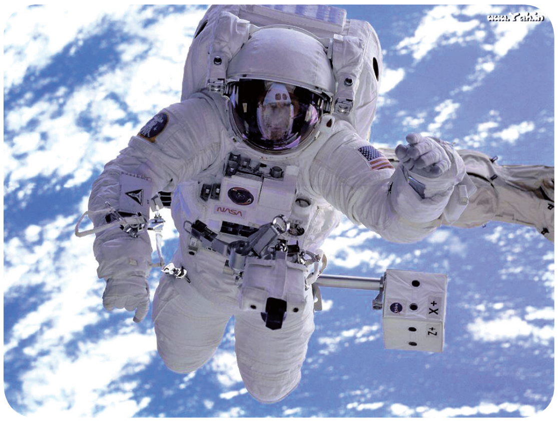


Figure 1.12 Weightlessness of astronauts

1.12.3 Application of Newton's law of gravitation

1) Dimensions of the heavenly bodies can be measured using the gravitation law. Mass of the Earth, radius of the Earth, acceleration due to gravity, etc. can be calculated with a higher accuracy.
2) Helps in discovering new stars and planets.
3) One of the irregularities in the motion of stars is called 'Wobble' lead to the disturbance in the motion of a planet nearby. In this condition the mass of the star can be calculated using the law of gravitation.
4) Helps to explain germination of roots is due to the property of geotropism which is the property of a root responding to the gravity.
5) Helps to predict the path of the astronomical bodies.

Points to Remember

- ❖ Mechanics is divided into statics and dynamics.
- ❖ Ability of a body to maintain its state of rest or motion is called Inertia.
- ❖ Moment of the couple is measured by the product of any one of the forces and the perpendicular distance between two forces.
- ❖ SI unit of force is newton (N). C.G.S unit is dyne.
- ❖ When a force F acts on a body for a period of time t, then the product of force and time is known as 'impulse'.
- ❖ The unit of weight is newton or kg f
- ❖ The weight of a body is more at the poles than at the equatorial region.
- ❖ Mass of a body is defined as the quantity of matter contained in the object. Its SI unit is kilogram (kg).
- ❖ Apparent weight is the weight of the body acquired due to the action of gravity and other external forces on the body.
- ❖ Whenever a body or a person falls freely under the action of Earth's gravitational force alone, it appears to have zero weight. This state is referred to as 'weightlessness'.

SOLVED PROBLEMS

Problem-1: Calculate the velocity of a moving body of mass 5 kg whose linear momentum is 2.5 $kg\,m\,s^{-1}$.

Solution: Linear momentum = mass × velocity

Velocity = linear momentum / mass.
$V = 2.5 / 5 = 0.5\ m\ s^{-1}$

Problem 2: A door is pushed, at a point whose distance from the hinges is 90 cm, with a force of 40 N. Calculate the moment of the force about the hinges.

Solution:

Formula: The moment of a force $M = F \times d$

Given: F = 40 N and d = 90 cm = 0.9 m.

Hence, moment of the force = 40 × 0.9 = 36 N m.

Problem 3 : At what height from the centre of the Earth the acceleration due to gravity will be ¼th of its value as at the Earth.

Solution:
Data: Height from the centre of the Earth, $R' = R + h$
The acceleration due to gravity at that height, $g' = g/4$

Formula: $g = GM/R^2$

$$\frac{g}{g'} = \left(\frac{R'}{R}\right)^2 = \left(\frac{R+h}{R}\right)^2 = \left(1 + \frac{h}{R}\right)^2$$

$$4 = \left(1 + \frac{h}{R}\right)^2,$$

$$2 = 1 + \frac{h}{R} \qquad \text{or } h = R. \qquad R' = 2R$$

From the centre of the Earth, the object is placed at twice the radius of the earth.

TEXTBOOK EVALUATION

5J3MGE

I. Choose the correct answer

1) Inertia of a body depends on
   a) weight of the object
   b) acceleration due to gravity of the planet
   c) mass of the object
   d) Both a & b
2) Impulse is equals to
   a) rate of change of momentum
   b) rate of force and time
   c) change of momentum
   d) rate of change of mass
3) Newton's III law is applicable
   a) for a body is at rest
   b) for a body in motion
   c) both a & b
   d) only for bodies with equal masses
4) Plotting a graph for momentum on the X-axis and time on Y-axis. slope of momentum-time graph gives
   a) Impulsive force b) Acceleration
   c) Force d) Rate of force
5) In which of the following sport the turning of effect of force used
   a) swimming b) tennis
   c) cycling d) hockey
6) The unit of 'g' is m s^{-2}. It can be also expressed as
   a) cm s^{-1} b) N kg^{-1}
   c) N m^2 kg^{-1} d) cm^2 s^{-2}
7) One kilogram force equals to
   a) 9.8 dyne b) 9.8×10^4 N
   c) 98×10^4 dyne d) 980 dyne
8) The mass of a body is measured on planet Earth as M kg. When it is taken to a planet of radius half that of the Earth then its value will be____kg
   a) 4 M b) 2M c) M/4 d) M
9) If the Earth shrinks to 50% of its real radius its mass remaining the same, the weight of a body on the Earth will
   a) decrease by 50% b) increase by 50%
   c) decrease by 25% d) increase by 300%
10) To project the rockets which of the following principle(s) is /(are) required?
   a) Newton's third law of motion
   b) Newton's law of gravitation
   c) law of conservation of linear momentum
   d) both a and c

II. Fill in the blanks

1. To produce a displacement ____________ is required
2. Passengers lean forward when sudden brake is applied in a moving vehicle. This can be explained by ____________
3. By convention, the clockwise moments are taken as ____________ and the anticlockwise moments are taken as____________
4. ____________ is used to change the speed of car.
5. A man of mass 100 kg has a weight of ____________ at the surface of the Earth

III. State whether the following statements are true or false. Correct the statement if it is false:

1. The linear momentum of a system of particles is always conserved.
2. Apparent weight of a person is always equal to his actual weight
3. Weight of a body is greater at the equator and less at the polar region.
4. Turning a nut with a spanner having a short handle is so easy than one with a long handle.
5. There is no gravity in the orbiting space station around the Earth. So the astronauts feel weightlessness.

IV. Match the following

Column I		Column II
a. Newton's I law	-	propulsion of a rocket
b. Newton's II law	-	Stable equilibrium of a body
c. Newton's III law	-	Law of force
d. Law of conservation of Linear momentum	-	Flying nature of bird

V. Assertion & Reasoning

Mark the correct choice as

(a) If both the assertion and the reason are true and the reason is the correct explanation of assertion.

(b) If both the assertion and the reason are true, but the reason is not the correct explanation of the assertion.

(c) Assertion is true, but the reason is false.

(d) Assertion is false, but the reason is true.

1. **Assertion:** The sum of the clockwise moments is equal to the sum of the anticlockwise moments.

   Reason: The principle of conservation of momentum is valid if the external force on the system is zero.

2. **Assertion:** The value of 'g' decreases as height and depth increases from the surface of the Earth.

   Reason: 'g' depends on the mass of the object and the Earth.

VI. Answer briefly.

1. Define inertia. Give its classification.
2. Classify the types of force based on their application.
3. If a 5 N and a 15 N forces are acting opposite to one another. Find the resultant force and the direction of action of the resultant force
4. Differentiate mass and weight.
5. Define moment of a couple.
6. State the principle of moments.
7. State Newton's second law.
8. Why a spanner with a long handle is preferred to tighten screws in heavy vehicles?
9. While catching a cricket ball the fielder lowers his hands backwards. Why?
10. How does an astronaut float in a space shuttle?

VII. Solve the given problems

1. Two bodies have a mass ratio of 3:4 The force applied on the bigger mass produces an acceleration of 12 ms^{-2}.What could be the acceleration of the other body, if the same force acts on it.
2. A ball of mass 1 kg moving with a speed of 10 ms^{-1} rebounds after a perfect elastic collision with the floor. Calculate the change in linear momentum of the ball.
3. A mechanic unscrew a nut by applying a force of 140 N with a spanner of length 40 cm. What should be the length of the spanner if a force of 40 N is applied to unscrew the same nut?
4. The ratio of masses of two planets is 2:3 and the ratio of their radii is 4:7 Find the ratio of their accelerations due to gravity.

VIII. Answer in detail.

1. What are the types of inertia? Give an example for each type.
2. State Newton's laws of motion?
3. Deduce the equation of a force using Newton's second law of motion.
4. State and prove the law of conservation of linear momentum.
5. Describe rocket propulsion.
6. State the universal law of gravitation and derive its mathematical expression
7. Give the applications of universal law gravitation.

IX. HOT Questions

1. Two blocks of masses 8 kg and 2 kg respectively lie on a smooth horizontal surface in contact with one other. They are pushed by a horizontally applied force of 15 N. Calculate the force exerted on the 2 kg mass.
2. A heavy truck and bike are moving with the same kinetic energy. If the mass of the truck is four times that of the bike, then calculate the ratio of their momenta. (Ratio of momenta = 1:2
3. "Wearing helmet and fastening the seat belt is highly recommended for safe journey" Justify your answer using Newton's laws of motion.

REFERENCE BOOKS

- Concept of physics-HC verma
- Interactive physics(Newton's law)MTG learning.

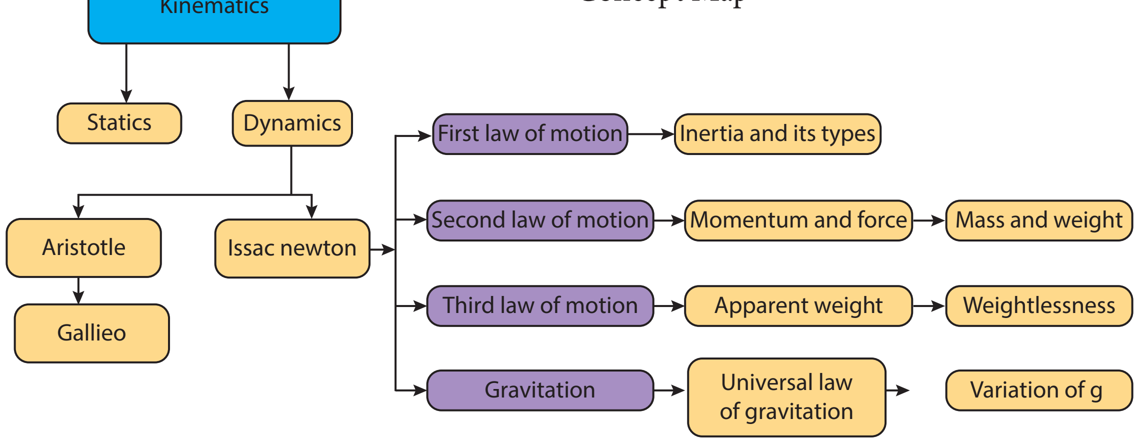
INTERNET RESOURCES

https://www.grc.nasa.gov

https://www.physicsclassroom.com

https://www.britannica.com/science/Newtons-law-of-gravitation

Concept Map



ICT CORNER

Newton's second law

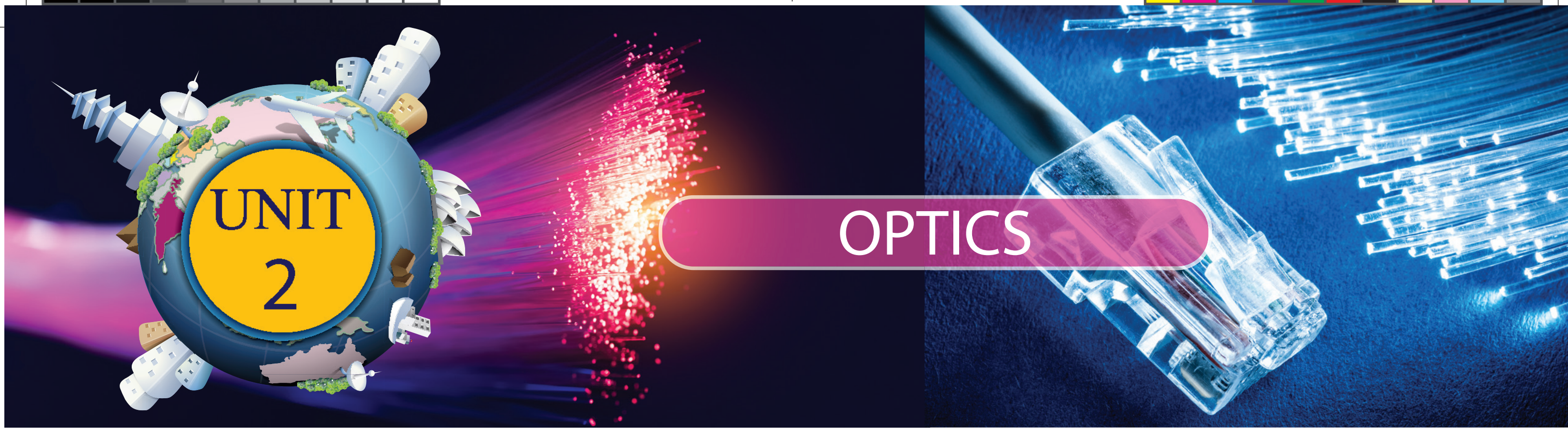
Steps

- Open the browser and type "olabs.edu.in" in the address bar. Click physics tab and then click "Newton's second " under class 9 section. Go to "simulator" tab to do the experiment.
- Select the desired Cart mass (M_1) and vertical mass (M_2) using respective slider. Also select the desired distance (s) by moving the slider. Click on the "Start" button to start the experiment.
- Observe the time and note it down. Calculate acceleration (a) of the cart using the formula $a = 2s/t^2$. Find the fore due to rate of change of momentum using (M_1+M_2) a.
- Calculate force $F = M_2$ g.
- You will observe $(M_1+M_2)a = M_2 g$. Hence Newton's Second Law is verified. Repeat the experiment with different masses. Also do this in different environment like Earth, Moon, Uranus and Jupiter. Click reset to restart the experiment.

Link

http://amrita.olabs.edu.in/?sub=1&brch=1&sim=44&cnt=4

B375_10_SCIENCE_EM



5JCII2

Learning Objectives

At the end of this lesson, students will be able to:

- state the laws of refraction.
- list the properties of light.
- explain the scattering of light and its various kinds.
- understand the images formed by concave and convex lens.
- analyze the ray diagram of concave and convex lens.
- understand the working of human eye and optical instruments
- solve numerical problems

INTRODUCTION

Light is a form of energy which travels in the form of waves. The path of light is called ray of light and group of these rays are called as beam of light. Any object which gives out light are termed as source of light. Some of the sources emit their own light and they are called as luminous objects. All the stars, including the Sun, are examples for luminous objects. We all know that we are able to see objects with the help of our eyes. But, we cannot see any object in a dark room. Can you explain why? If your answer is 'we need light to see objects', the next question is 'if you make the light from a torch to fall on your eyes, will you be able to see the objects?' Definitely, 'NO'. We can see the objects only when the light is made to fall on the objects and the light reflected from the objects is viewed by our eyes. You would have studied about the reflection and refraction of light elaborately in your previous classes. In this chapter, we shall discuss about the scattering of light, images formed by convex and concave lenses, human eye and optical instruments such as telescopes and microscopes.

2.1 PROPERTIES OF LIGHT

Let us recall the properties of light and the important aspects on refraction of light.

1. Light is a form of energy.
2. Light always travels along a straight line.
3. Light does not need any medium for its propagation. It can even travel through vacuum.
4. The speed of light in vacuum or air is, $c = 3 \times 10^8$ ms^{-1}.
5. Since, light is in the form of waves, it is characterized by a wavelength (λ) and a frequency (ν), which are related by the following equation: $c = \nu \lambda$ (c - velocity of light).

6. Different coloured light has different wavelength and frequency.
7. Among the visible light, violet light has the lowest wavelength and red light has the highest wavelength.
8. When light is incident on the interface between two media, it is partly reflected and partly refracted.

2.2 REFRACTION OF LIGHT

When a ray of light travels from one transparent medium into another obliquely, the path of the light undergoes deviation. This deviation of ray of light is called refraction. Refraction takes place due to the difference in the velocity of light in different media. The velocity of light is more in a rarer medium and less in a denser medium. Refraction of light obeys two laws of refraction.

2.2.1 First law of refraction:

The incident ray, the refracted ray of light and the normal to the refracting surface all lie in the same plane.

2.2.2 Second law of refraction:

The ratio of the sine of the angle of incidence and sine of the angle of refraction is equal to the ratio of refractive indices of the two media. This law is also known as Snell's law.

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \quad \cdots\cdots\cdots\cdots \quad (2.1)$$

- Refractive index gives us an idea of how fast or how slow light travels in a medium. The ratio of speed of light in vacuum to the speed of light in a medium is defined as refractive index 'μ' of that medium.
- The speed of light in a medium is low if the refractive index of the medium is high and vice versa.
- When light travels from a denser medium into a rarer medium, the refracted ray is bent away from the normal drawn to the interface.
- When light travels from a rarer medium into a denser medium, the refracted ray is bent towards the normal drawn to the interface.

2.3 REFRACTION OF A COMPOSITE LIGHT- DISPERSION OF LIGHT

We know that Sun is the fundamental and natural source of light. If a source of light produces a light of single colour, it is known as a monochromatic source. On the other hand, a composite source of light produces a white light which contains light of different colours. Sun light is a composite light which consists of light of various colours or wavelengths. Another example for a composite source is a mercury vapour lamp. What do you observe when a white light is refracted through a glass prism?

When a beam of white light or composite light is refracted through any transparent media such as glass or water, it is split into its component colours. This phenomenon is called as 'dispersion of light'.

The band of colours is termed as spectrum. This spectrum consists of following colours: Violet, Indigo, Blue, Green, Yellow, Orange, and Red. These colours are represented by the acronym "VIBGYOR". Why do we get the spectrum when white light is refracted by a transparent medium? This is because, different coloured lights are bent through different angles. That is the angle of refraction is different for different colours.

Angle of refraction is the smallest for red and the highest for violet. From Snell's law, we know that the angle of refraction is determined in terms of the refractive index of the medium. Hence, the refractive index of the medium is different for different coloured lights. This indicates that the refractive index of a medium is dependent on the wavelength of the light.

2.4 SCATTERING OF LIGHT

When sunlight enters the Earth's atmosphere, the atoms and molecules of different gases present in the atmosphere refract the light in all possible directions. This is called as 'Scattering of light'. In this phenomenon, the beam of light is redirected in all directions when it interacts with a particle of medium. The interacting particle of the medium is called as 'scatterer'.

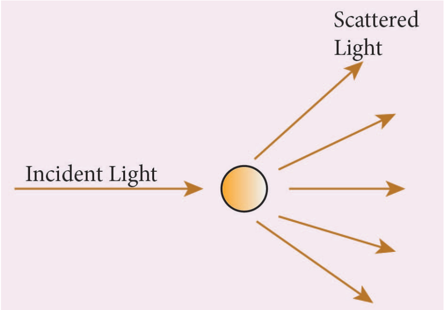


Figure 2.1 Scattering of light

2.4.1 Types of scattering

When a beam of light, interacts with a constituent particle of the medium, it undergoes many kinds of scattering. Based on initial and final energy of the light beam, scattering can be classified as,

1) Elastic scattering 2) Inelastic scattering

1) Elastic scattering

If the energy of the incident beam of light and the scattered beam of light are same, then it is called as 'elastic scattering'.

2) Inelastic scattering

If the energy of the incident beam of light and the scattered beam of light are not same, then it is called as 'inelastic scattering'. The nature and size of the scatterer results in different types of scattering. They are

- Rayleigh scattering
- Mie scattering
- Tyndall scattering
- Raman scattering

Rayleigh scattering

The scattering of sunlight by the atoms or molecules of the gases in the earth's atmosphere is known as Rayleigh scattering.

Rayleigh's scattering law

Rayleigh's scattering law states that, "The amount of scattering of light is inversely proportional to the fourth power of its wavelength".

Amount of scattering 'S' $\propto \frac{1}{\lambda^4}$

According to this law, the shorter wavelength colours are scattered much more than the longer wavelength colours.

When sunlight passes through the atmosphere, the blue colour (shorter wavelength) is scattered to a greater extent than the red colour (longer wavelength). This scattering causes the sky to appear in blue colour.

At sunrise and sunset, the light rays from the Sun have to travel a larger distance in the atmosphere than at noon. Hence, most of the blue lights are scattered away and only the red light which gets least scattered reaches us. Therefore, the colour of the Sun is red at sunrise and sunset.

Mie scattering

Mie scattering takes place when the diameter of the scatterer is similar to or larger than the wavelength of the incident light. It is also an elastic scattering. The amount of scattering is independent of wave length.

Mie scattering is caused by pollen, dust, smoke, water droplets, and other particles in the lower portion of the atmosphere.

Mie scattering is responsible for the white appearance of the clouds. When white light falls on the water drop, all the colours are equally scattered which together form the white light.

10th_Science_Unit-2.indd 18 21-02-2019 18:34:37

Tyndall Scattering

When a beam of sunlight, enters into a dusty room through a window, then its path becomes visible to us. This is because, the tiny dust particles present in the air of the room scatter the beam of light. This is an example of Tyndall Scattering

The scattering of light rays by the colloidal particles in the colloidal solution is called Tyndall Scattering or Tyndall Effect.

> **Do you Know**
>
> **Colloid** is a microscopically small substance that is equally dispersed throughout another material. Example: Milk, Ice cream, muddy water, smoke

Raman scattering

When a parallel beam of monochromatic (single coloured) light passes through a gas or liquid or transparent solid, a part of light rays are scattered.

The scattered light contains some additional frequencies (or wavelengths) other than that of incident frequency (or wavelength). This is known as Raman scattering or Raman Effect.

Raman Scattering is defined as "*The interaction of light ray with the particles of pure liquids or transparent solids, which leads to a change in wavelength or frequency.*"

The spectral lines having frequency equal to the incident ray frequency is called 'Rayleigh line' and the spectral lines which are having frequencies other than the incident ray frequency are called 'Raman lines'. The lines having frequencies lower than the incident frequency is called stokes lines and the lines having frequencies higher than the incident frequency are called Antistokes lines.

You will study more about Raman Effect in higher classes.

2.5 LENSES

A lens is an optically transparent medium bounded by two spherical refracting surfaces or one plane and one spherical surface.

Lens is basically classified into two types. They are: (i) Convex Lens (ii) Concave Lens

(i) **Convex or bi-convex lens:** It is a lens bounded by two spherical surfaces such that it is thicker at the centre than at the edges. A beam of light passing through it, is converged to a point. So, a convex lens is also called as converging lens.

(ii) **Concave or bi-concave Lens:** It is a lens bounded by two spherical surfaces such that it is thinner at the centre than at the edges. A parallel beam of light passing through it, is diverged or spread out. So, a concave lens is also called as diverging lens.

2.5.1 Other types of Lenses

Plano-convex lens: If one of the faces of a bi-convex lens is plane, it is known as a plano-convex lens.

Plano-concave lens: If one of the faces of a bi-concave lens is plane, it is known as a plano-concave lens.

All these lenses are shown in Figure 2.2 given below:

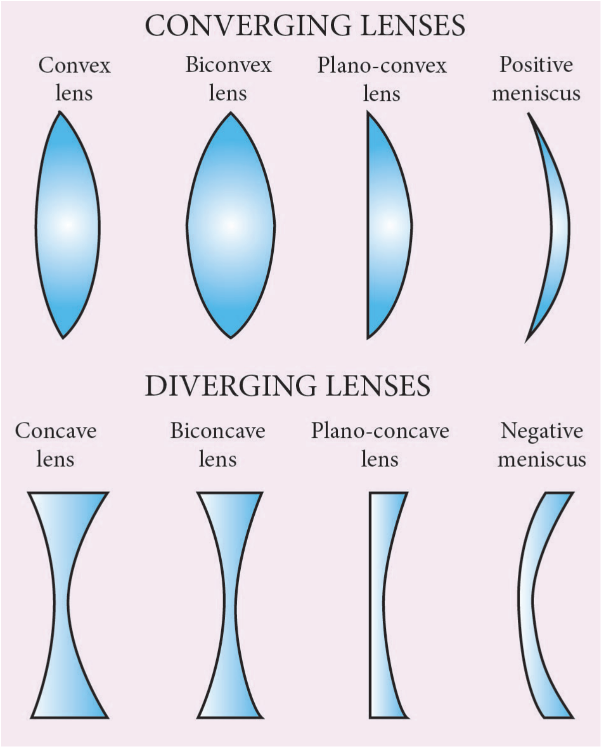


Figure 2.2 Types of lenses

2.6 IMAGES FORMED DUE TO REFRACTION THROUGH A CONVEX AND CONCAVE LENS

When an object is placed in front of a lens, the light rays from the object fall on the lens. The position, size and nature of the image formed can be understood only if we know certain basic rules.

Rule-1: When a ray of light strikes the convex or concave lens obliquely at its optical centre, it continues to follow its path without any deviation (Figure 2.3).

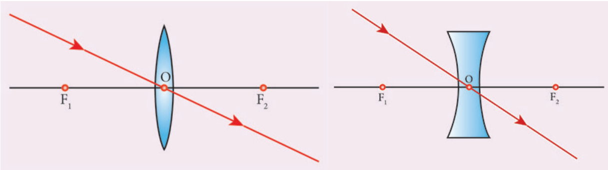


Figure 2.3 Rays passing through the optical centre

Rule-2: When rays parallel to the principal axis strikes a convex or concave lens, the refracted rays are converged to (convex lens) or appear to diverge from (concave lens) the principal focus (Figure 2.4).

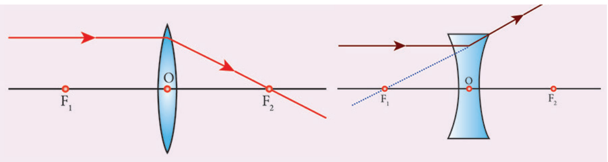


Figure 2.4 Rays passing parallel to the optic axis

Rule-3: When a ray passing through (convex lens) or directed towards (concave lens) the principal focus strikes a convex or concave lens, the refracted ray will be parallel to the principal axis (Figure 2.5).

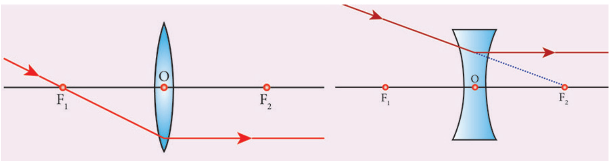


Figure 2.5 Rays passing through or directed towards the principal focus

2.7 REFRACTION THROUGH A CONVEX LENS

Let us discuss the formation of images by a convex lens when the object is placed at various positions.

5YLHHQ

Object at infinity

When an object is placed at infinity, a real image is formed at the principal focus. The size of the image is much smaller than that of the object (Figure 2.6).

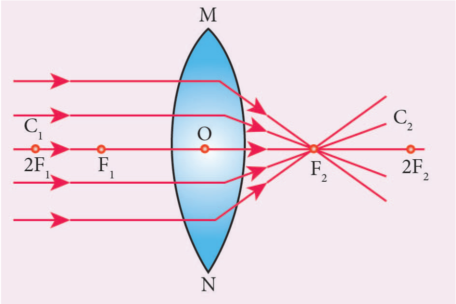


Figure 2.6 Object at infinity

Object placed beyond C (>2F)

When an object is placed behind the center of curvature(beyond C), a real and inverted image is formed between the center of curvature and the principal focus. The size of the image is the same as that of the object (Figure 2.7).

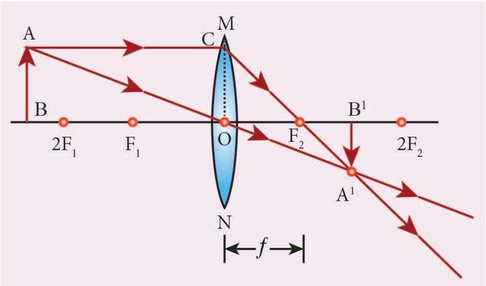


Figure 2.7 Object placed beyond C (>2F)

Object placed at C

When an object is placed at the center of curvature, a real and inverted image is formed at the other center of curvature. The size of the image is the same as that of the object (Figure 2.8).

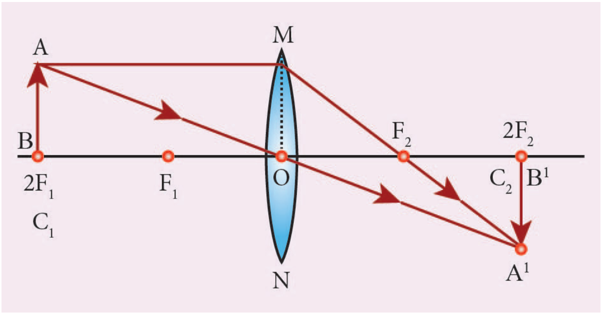


Figure.2.8 Object placed at C

Object placed between F and C

When an object is placed in between the center of curvature and principal focus, a real and inverted image is formed behind the center of curvature. The size of the image is bigger than that of the object (Figure 2.9).

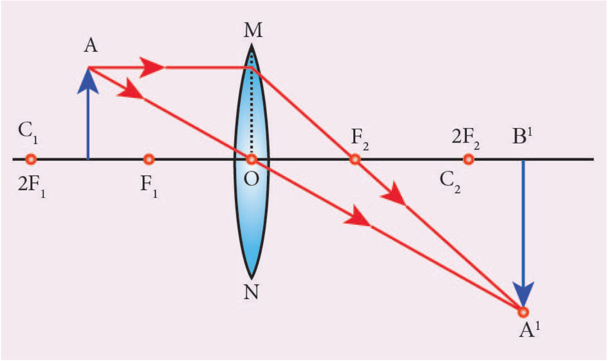


Figure 2.9 Object placed between F and C

Object placed at the principal focus F

When an object is placed at the focus, a real image is formed at infinity. The size of the image is much larger than that of the object (Figure 2.10).

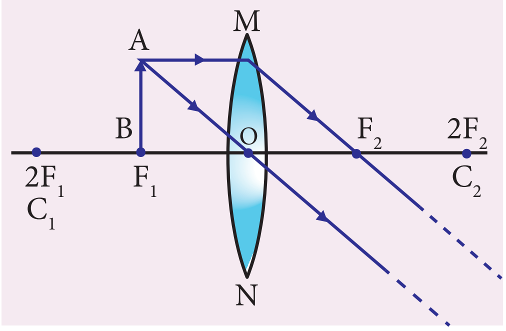


Figure 2.10 Object placed at the principal focus F

Object placed between the principal focus F and optical centre O

When an object is placed in between principal focus and optical centre, a virtual image is formed. The size of the image is larger than that of the object (Figure 2.11).

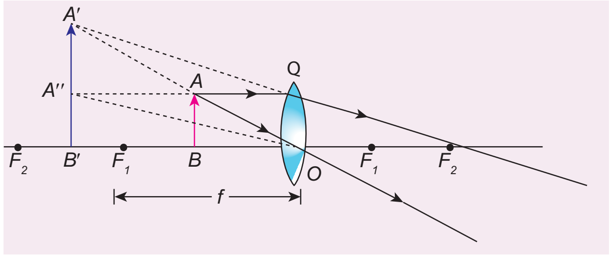


Figure 2.11 Object placed between the principal focus F and optical centre O

2.8 APPLICATIONS OF CONVEX LENSES

1. Convex lenses are used as camera lenses
2. They are used as magnifying lenses
3. They are used in making microscope, telescope and slide projectors
4. They are used to correct the defect of vision called hypermetropia

2.9 REFRACTION THROUGH A CONCAVE LENS

Let us discuss the formation of images by a concave lens when the object is placed at two possible positions.

Object at Infinity

When an object is placed at infinity, a virtual image is formed at the focus. The size of the image is much smaller than that of the object (Figure 2.12).

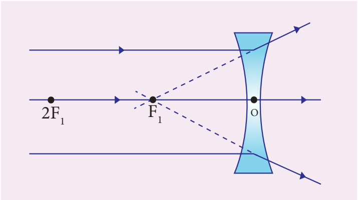


Figure 2.12 Concave lens-Object at infinity

Object anywhere on the principal axis at a finite distance

When an object is placed at a finite distance from the lens, a virtual image is formed between optical center and focus of the concave lens. The size of the image is smaller than that of the object (Figure 2.13).

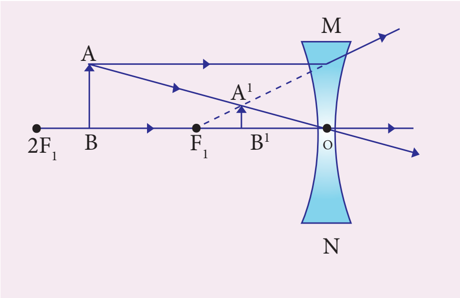


Figure 2.13 Concave lens-Object at a finite distance

But, as the distance between the object and the lens is decreased, the distance between the image and the lens also keeps decreasing. Further, the size of the image formed increases as the distance between the object and the lens is decreased. This is shown in (figure 2.14).

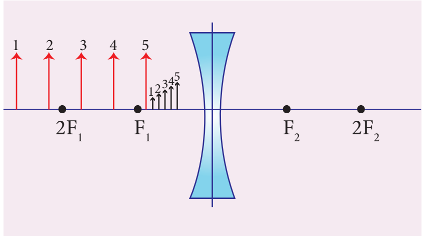


Figure 2.14 Concave lens-Variation in position and size of image with object distance

2.10 APPLICATIONS OF CONCAVE LENSES

1. Concave lenses are used as eye lens of 'Galilean Telescope'
2. They are used in wide angle spy hole in doors.
3. They are are used to correct the defect of vision called 'myopia'

2.11 LENS FORMULA

Like spherical mirrors, we have lens formula for spherical lenses. The lens formula gives the relationship among distance of the object (u), distance of the image (v) and the focal length (f) of the lens. It is expressed as

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \ldots\ldots\ldots\ldots\ 2.2$$

It is applicable to both convex and concave lenses. We need to give an at most care while solving numerical problems related to lenses in taking proper signs of different quantities.

2.12 SIGN CONVENTION

Cartesian sign conventions are used for measuring the various distances in the ray diagrams of spherical lenses. According to cartesian sign convention,

1. The object is always placed on the left side of the lens.
2. All the distances are measured from the optical centre of the lens.
3. The distances measured in the same direction as that of incident light are taken as positive.
4. The distances measured against the direction of incident light are taken as negative.
5. The distances measured upward and perpendicular to the principal axis is taken as positive.
6. The distances measured downward and perpendicular to the principal axis is taken as negative.

2.13 MAGNIFICATION OF A LENS

Like spherical mirrors, we have magnification for spherical lenses. Spherical lenses produce magnification and it is defined as the ratio of the height of the image to the height of an object. Magnification is denoted by the letter 'm'. If height of the object is h and height of the image is h', the magnification produced by lens is,

$$m = \frac{\textit{height of the image}}{\textit{height of the object}} = \frac{h'}{h} \quad \ldots\ldots (2.3)$$

Also it is related to the distance of the object (u) and the distance of the image (v) as follows:

$$m = \frac{\textit{Distance of the image}}{\textit{Distance of the object}} = \frac{v}{u} \quad \ldots\ldots (2.4)$$

If the magnification is greater than 1, then we get an enlarged image. On the other hand, if the magnification is less than 1, then we get a diminished image.

2.14 LENS MAKER'S FORMULA

All lenses are made up of transparent materials. Any optically transparent material will have a refractive index. The lens formula relates the focal length of a lens with the distance of object and image. For a maker of any lens, knowledge of radii of curvature of the lens is required. This clearly indicates the need for an equation relating the radii of curvature of the lens, the refractive index of the given material of the lens and the required focal length of the lens. The lens maker's formula is one such equation. It is given as

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \cdots\cdots\cdots (2.5)$$

where μ is the refractive index of the material of the lens; R_1 and R_2 are the radii of curvature of the two faces of the lens; f is the focal length of the lens.

2.15 POWER OF A LENS

When a ray of light falls on a lens, the ability to converge or diverge these light rays depends on the focal length of the lens. This ability of a lens to converge (convex lens) or diverge (concave lens) is called as its power. Hence, the power of a lens can be defined as the degree of convergence or divergence of light rays. Power of a lens is numerically defined as the reciprocal of its focal length.

$$P = \frac{1}{f} \cdots\cdots\cdots\cdots\cdots (2.6)$$

The SI unit of power of a lens is dioptre. It is represented by the symbol D. If focal length is expressed in 'm', then the power of lens is expressed in 'D'. Thus 1D is the power of a lens, whose focal length is 1metre. $1D = 1m^{-1}$.

By convention, the power of a convex lens is taken as positive whereas the power of a concave lens is taken, as negative.

More to Know

The lens formula and lens maker's formula are applicable to only thin lenses. In the case of thick lenses, these formulae with little modifications are used.

Table 2.1 Differences between a Convex Lens and a Concave Lens

S. No	Convex Lens	Concave Lens
1	A convex lens is thicker in the middle than at edges.	A concave lens is thinner in the middle than at edges.
2	It is a converging lens.	It is a diverging lens.
3	It produces mostly real images.	It produces virtual images.
4	It is used to treat hypermeteropia.	It is used to treat myopia.

2.16 HUMAN EYE

The human eyes are most valuable and sensitive organs responsible for vision. They are the gateway to the wonderful world.

Structure of the eye

The eye ball is approximately spherical in shape with a diameter of about 2.3 cm. It consists of a tough membrane called sclera, which protects the internal parts of the eye.

Important parts of human eye are

Cornea: This is the thin and transparent layer on the front surface of the eyeball as shown in figure 2.15. It is the main refracting surface. When light enters through the cornea, it refracts or bends the light on to the lens.

Iris: It is the coloured part of the eye. It may be blue, brown or green in colour. Every person has a unique colour, pattern and texture. Iris controls amount of light entering into the pupil like camera aperture.

Pupil: It is the centre part of the Iris. It is the pathway for the light to retina.

Retina: This is the back surface of the eye. It is the most sensitive part of human eye, on which real and inverted image of objects is formed.

Ciliary muscles – Eye lens is fixed between the ciliary muscles. It helps to change the focal length of the eye lens according to the position of the object.

Eye Lens – It is the important part of human eye. It is convex in nature.

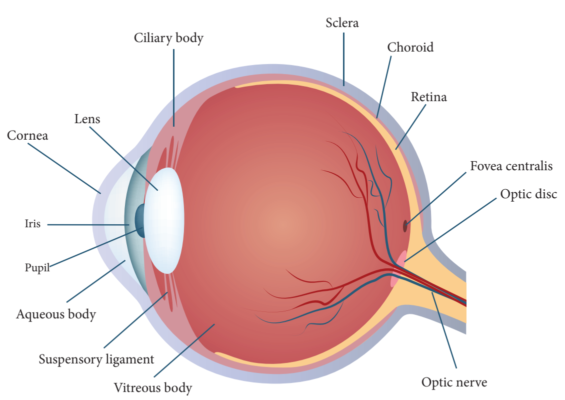


Figure 2.15 Human eye

Working of the eye

The transparent layer cornea bends the light rays through pupil located at the centre part of the Iris. The adjusted light passes through the eye lens. Eye lens is convex in nature. So, the light rays from the objects are converged and a real and inverted image is formed on retina. Then, retina passes the received real and inverted image to the brain through optical nerves. Finally, the brain senses it as erect image.

Power of Accommodation

The ability of the eye lens to focus nearby as well as the distant objects is called power of accommodation of the eye. This is achieved by changing the focal length of the eye lens with the help of ciliary muscles.

Eye lens is made of a flexible, jelly-like material. By relaxing and contracting the ciliary muscle, the curvature and hence the focal length of the eye lens can be altered. When we see distant objects, the ciliary muscle relaxes and makes the eye lens thinner. This increases the focal length of the eye lens. Hence, the distant object can be clearly seen. On the other hand, when we look at a closer object, the focal length of the eye lens is decreased by the contraction of ciliary muscle. Thus, the image of the closer object is clearly formed on the retina.

Persistence of vision

If the time interval between two consecutive light pulses is less than 0.1 second, human eye cannot distinguish them separately. It is called persistence of vision.

The far point and near point of the human eye

The minimum distance required to see the objects distinctly without strain is called least distance of distinct vision. It is called as near point of eye. It is 25 cm for normal human eye.

10th_Science_Unit-2.indd 24
21-02-2019 18:34:38

The maximum distance up to which the eye can see objects clearly is called as far point of the eye. It is infinity for normal eye.

2.17 DEFECTS IN EYE

A normal human eye can clearly see all the objects placed between 25cm and infinity. But, for some people, the eye loses its power of accommodation. This could happen due to many reasons including ageing. Hence, their vision becomes defective. Let us discuss some of the common defects of human eye.

Myopia

Myopia, also known as short sightedness, occurs due to the lengthening of eye ball. With this defect, nearby objects can be seen clearly but distant objects cannot be seen clearly. The focal length of eye lens is reduced or the distance between eye lens and retina increases. Hence, the far point will not be infinity for such eyes and the far point has come closer. Due to this, the image of distant objects are formed before the retina (Figure 2.16-a). This defect can be corrected using a concave lens (Figure 2.16-b). The focal length of the concave lens to be used is computed as follows:

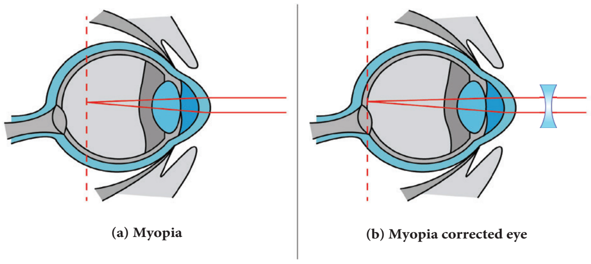


Figure 2.16 (a) Vision with myopia
b) Corrected vision using a concave lens

Let a person with myopia eye can see up to a distance x. Suppose that he wants to see all objects farther than this distance, i.e., up to infinity. Then the focal length of the required concave lens is f = −x. If the person can see up to a distance x and he wants to see up to a distance y, then, the focal length of the required concave lens is,

$$f = \frac{xy}{x-y} \quad \ldots\ldots\ldots\ldots\ldots (2.7)$$

Hypermeteropia

Hypermeteropia, also known as long sightedness, occurs due to the shortening of eye ball. With this defect, distant objects can be seen clearly but nearby objects cannot be seen clearly. The focal length of eye lens is increased or the distance between eye lens and retina decreases. Hence, the near point will not be at 25cm for such eyes and the near point has moved farther. Due to this, the image of nearby objects are formed behind the retina (Figure 2.17-a). This defect can be corrected using a convex lens (Figure 2.17-b). The focal length of the convex lens to be used is computed as follows:

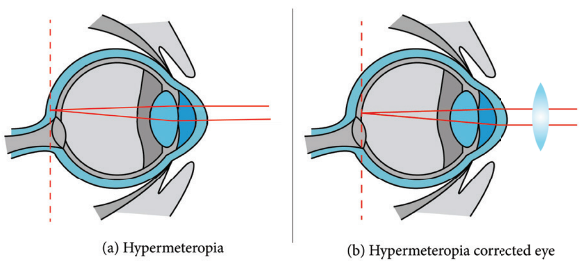


Figure 2.17 (a) Vision with hypermeteropia
(b) Corrected vision using a convex lens

Let a person with hypermeteropia eye can see object beyond a distance d. Suppose that he wants to see all objects closer than this distance up to a distance D. Then, the focal length of the required convex lens is

$$f = \frac{dD}{d-D} \quad \ldots\ldots\ldots\ldots\ldots (2.8)$$

Presbyopia

Due to ageing, ciliary muscles become weak and the eye-lens become rigid (inflexible) andso the eye loses its power of accommodation.

Because of this, an aged person cannot see the nearby objects clearly. So, it is also called as 'old age hypermetropia'.

Some persons may have both the defects of vision - myopia as well as hypermetropia. This can be corrected by 'bifocal lenses'. In which, upper part consists of concave lens (to correct myopia) used for distant vision and the lower part consists of convex lens (to correct hypermetropia) used for reading purposes.

Astigmatism

In this defect, eye cannot see parallel and horizontal lines clearly. It may be inherited or acquired. It is due to the imperfect structure of eye lens because of the development of cataract on the lens, ulceration of cornea, injury to the refracting surfaces, etc. Astigmatism can be corrected by using cylindrical lenses (Torrid lenses).

2.18 MICROSCOPE

This is an optical instrument, which helps us to see tiny (very small) objects. It is classified as

1. Simple microscope
2. Compound microscope

Simple Microscope

Simple microscope has a convex lens of short focal length. It is held near the eye to get enlarged image of small objects.

Let an object (AB) is placed at a point within the principal focus (u < f) of the convex lens and the observer's eye is placed just behind

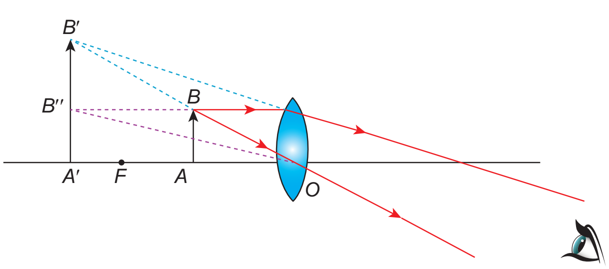


Figure 2.18 Image formation in simple microscope

the lens. As per this position the convex lens produces an erect, virtual and enlarged image (A'B'). The image formed is in the same side of the object and the distance equal to the least distance of distinct vision (D) (For normal human eye D = 25 cm).

Uses of Simple microscope

Simple microscopes are used

a) by watch repairers and jewellers.
b) to read small letters clearly.
c) to observe parts of flower, insects etc.
d) to observe finger prints in the field of forensic science.

Compound microscope

Compound microscope is also used to see the tiny objects. It has better magnification power than simple microscope.

Magnification power of microscopes can be increased by decreasing the focal length of the lens used. Due to constructional limitations, the focal length of the lens cannot be decreased beyond certain limit. This problem can be solved by using two separate biconvex lenses.

Construction

A compound microscope consists of two convex lenses. The lens with the shorter focal length is placed near the object, and is called as 'objective lens' or 'objective piece'. The lens with larger focal length and larger aperture placed near the observer's eye is called as 'eye lens' or 'eye piece'. Both the lenses are fixed in a narrow tube with adjustable provision.

Working

The object (AB) is placed at a distance slightly greater than the focal length of objective lens ($u > f_o$). A real, inverted and magnified image (A'B') is formed at the other

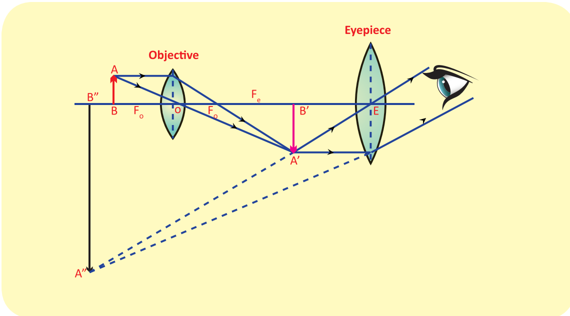


Figure 2.19 Image formation in compound microscope

side of the objective lens. This image behaves as the object for the eye lens. The position of the eye lens is adjusted in such a way, that the image (A'B') falls within the principal focus of the eye piece. This eye piece forms a virtual, enlarged and erect image (A″B″) on the same side of the object

Compound microscope has 50 to 200 times more magnification power than simple microscope

Travelling Microscope

A **travelling microscope** is one of the best instrument for measuring very small length with high degree of accuracy at the order of 0.01mm. It works based on the principle of vernier. Its least count is 0.01 mm.

2.19 TELESCOPE

Have you seen the recent lunar eclipse? With our naked eye we can't visualize the phenomena distinctly. Then, how can we see the distant object in clearer manner? It is possible with telescope.

Telescope is an optical instrument to see the distant objects. The first telescope was invented by Johann Lippershey in 1608. Galileo made a telescope to observe distant stars. He got the idea, from a spectacle maker who one day observed that the distant weather cock appeared magnified through his lens system fitted in his shop. Galileo observed the satellites of Jupiter and the rings of Saturn through his telescope. Kepler invented Telescope in 1611 which was fundamentally similar to the astronomical telescope.

Types of Telescope

According to optical property, it is classified into two groups:

i) refracting telescope ii) reflecting telescope

In **refracting telescope** lenses are used. Galilean telescope, Keplerian telescope, Achromatic refractors, are some refracting telescopes.

In **reflecting telescope** parabolic mirrors are used Gregorian, Newtonian, Cassegrain telescope are some **Reflecting telescopes**

According to the things which are observed, **Astronomical Telescope** and **Terrestrial Telescopes** are the two major types of telescope.

Astronomical Telescope

An astronomical telescope is used to view heavenly bodies like stars, planets galaxies and satellites.

Terrestrial Telescopes

The image in an astronomical telescope is inverted. So, it is not suitable for viewing objects on the surface of the Earth. Therefore, a terrestrial telescope is used. It provides an erect image. The major difference between astronomical and terrestrial telescope is erecting the final image with respect to the object.

Advantages of Telescopes

- Elaborate view of the Galaxies, Planets, stars and other heavenly bodies is possible.
- Camera can be attached for taking photograph for the celestial objects.
- Telescope can be viewed even with the low intensity of light.

Disadvantages

- Frequent maintenances needed.
- It is not easily portable one.

Points to Remember

- Light is a form of energy which travels along a straight line
- The deviation in the path of light ray is called refraction.
- The ratio of speed of light in vacuum to the speed of light in a medium is defined as refractive index 'μ' of that medium.
- Lens formula

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

- Magnification (m) $=\frac{h'}{h}=\frac{v}{u}$
- Power of lens. P $=\frac{1}{f}$
- The ability of the eye to focus nearby as well as the distant objects is called power of accommodation of the eye.
- A microscope is an optical instrument which helps us to see the objects which are very small in dimension.
- Telescope is an optical instrument used to see the distant objects clearly.

SOLVED PROBLEMS

Problem 1

Light rays travel from vacuum into a glass whose refractive index is 1.5. If the angle of incidence is 30°, calculate the angle of refraction inside the glass.

Solution:

accorting to Snell's law,

$$\frac{\sin i}{\sin r}=\frac{\mu_2}{\mu_1}$$

$$\mu_1 \sin i = \mu_2 \sin r$$

Here $\mu_1 = 1.0$, $\mu_2 = 1.5$, $i = 30°$

$$(1.0)\sin 30° = 1.5 \sin r$$

$$1\times\frac{1}{2} = 1.5 \sin r$$

$$\sin r = \frac{1}{2\times1.5} = \frac{1}{3} = (0.333)$$

$$r = \sin^{-1}(0.333)$$

$$r = 19.45°$$

Problem-2

A beam of light passing through a diverging lens of focal length 0.3m appear to be focused at a distance 0.2m behind the lens. Find the position of the object.

Solution:

$f = -0.3$ m, $v = -0.2$ m

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

$$\frac{1}{u}=\frac{1}{v}-\frac{1}{f}$$

$$\frac{1}{u}=\frac{1}{-0.2}-\frac{1}{-0.3}=\frac{-10}{6}$$

$$u=\frac{-6}{10}=-0.6 \text{ m}$$

Problem-3

A person with myopia can see objects placed at a distance of 4m. If he wants to see objects at a distance of 20m, what should be the focal length and power of the concave lens he must wear?

Solution:

Given that x = 4m and y = 20m.

Focal length of the correction lens is

$$f=\frac{xy}{x-y} \quad \text{(Refer eqn.2.7)}$$

$$f=\frac{4\times 20}{4-20}=\frac{80}{-16}=-5 \text{ m}$$

Power of the correction lens

$$=\frac{1}{f}=-\frac{1}{5}=-0.2 \text{ D}$$

Problem-4

For a person with hypermeteropia, the near point has moved to 1.5m. Calculate the focal length of the correction lens in order to make his eyes normal.

Solution:

Given that, d = 1.5m; D = 25cm = 0.25m (For a normal eye).

From equation (2.8), the focal length of the correction lens is

$$f=\frac{d\times D}{d-D}=\frac{1.5\times 0.25}{1.5-0.25}=\frac{0.375}{1.25}=0.3 \text{ m}$$

6E5CJ2

TEXTBOOK EVALUATION

I. Choose the correct answer

1. The refractive index of four substances A, B, C and D are 1.31, 1.43, 1.33, 2.4 respectively. The speed of light is maximum in
   a) A b) B c) C d) D
2. Where should an object be placed so that a real and inverted image of same size is obtained by a convex lens
   a) f b) 2f
   c) infinity d) between f and 2f
3. A small bulb is placed at the principal focus of a convex lens. When the bulb is switched on, the lens will produce
   a) a convergent beam of light
   b) a divergent beam of light
   c) a parallel beam of light
   d) a coloured beam of light
4. Magnification of a convex lens is
   a) Positive b) negative
   c) either positive or negative d) zero
5. A convex lens forms a real, diminished point sized image at focus. Then the position of the object is at
   a) focus b) infinity
   c) at 2f d) between f and 2f
6. Power of a lens is –4D, then its focal length is
   a) 4m b) –40m
   c) –0.25 m d) –2.5 m
7. In a myopic eye, the image of the object is formed
   a) behind the retina b) on the retina
   c) in front of the retina d) on the blind spot
8. The eye defect 'presbyopia' can be corrected by
   a) convex lens b) concave lens
   c) convex mirror d) Bi focal lenses
9. Which of the following lens would you prefer to use while reading small letters found in a dictionary?
   a) A convex lens of focal length 5 cm
   b) A concave lens of focal length 5 cm
   c) A convex lens of focal length 10 cm
   d) A concave lens of focal length 10 cm
10. If V_B, V_G, V_R be the velocity of blue, green and red light respectively in a glass prism, then which of the following statement gives the correct relation?
   a) $V_B = V_G = V_R$ b) $V_B > V_G > V_R$
   c) $V_B < V_G < V_R$ d) $V_B < V_G > V_R$

II. Fill in the blanks:

1. The path of the light is called as ________
2. The refractive index of a transparent medium is always greater than ________
3. If the energy of incident beam and the scattered beam are same, then the scattering of light is called as ________ scattering.
4. According to Rayleigh's scattering law, the amount of scattering of light is inversely proportional to the fourth power of its ________
5. Amount of light entering into the eye is controlled by ________

III. True or False. If false correct it.

1. Velocity of light is greater in denser medium than in rarer medium
2. The power of lens depends on the focal length of the lens
3. Increase in the converging power of eye lens cause 'hypermetropia'
4. The convex lens always gives small virtual image.

IV. Match the following:

	Column - I		Column - II
1	Retina	a	Path way of light
2	Pupil	b	Far point comes closer
3	Ciliary muscles	c	near point moves away
4	Myopia	d	Screen of the eye
5	Hypermetropia	f	Power of accommodation

V. Assertion and reasoning type

Mark the correct choice as

a) If both assertion and reason are true and reason is the correct explanation of assertion.

b) If both assertion and reason are true but reason is not the correct explanation of assertion.

c) Assertion is true but reason is false.

d) Assertion is false but reason is true.

1. **Assertion:** If the refractive index of the medium is high (denser medium) the velocity of the light in that medium will be small

   Reason: Refractive index of the medium is inversely proportional to the velocity of the light

2. **Assertion:** Myopia is due to the increase in the converging power of eye lens.

   Reason: Myopia can be corrected with the help of concave lens.

VI. Answer Briefly

1. What is refractive index?
2. State Snell's law.
3. Draw a ray diagram to show the image formed by a convex lens when the object is placed between F and 2F.
4. Define dispersion of light
5. State Rayleigh's law of scattering
6. Differentiate convex lens and concave lens.
7. What is power of accommodation of eye?
8. What are the causes of 'Myopia'?
9. Why does the sky appear in blue colour?
10. Why are traffic signals red in colour?

VII. Give the answer in detail

1. List any five properties of light
2. Explain the rules for obtaining images formed by a convex lens with the help of ray diagram.
3. Differentiate the eye defects: Myopia and Hypermetropia
4. Explain the construction and working of a 'Compound Microscope'.

VIII. Numerical Problems:

1. An object is placed at a distance 20cm from a convex lens of focal length 10cm. Find the image distance and nature of the image.
2. An object of height 3cm is placed at 10cm from a concave lens of focal length 15cm. Find the size of the image.

IX. Higher order thinking (HOT) questions:

1. While doing an experiment for the determination of focal length of a convex lens, Raja Suddenly dropped the lens. It got broken into two halves along the axis. If he continues his experiment with the same lens, (a) can he get the image? (b) Is there any change in the focal length?
2. The eyes of the nocturnal birds like owl are having a large cornea and a large pupil. How does it help them?

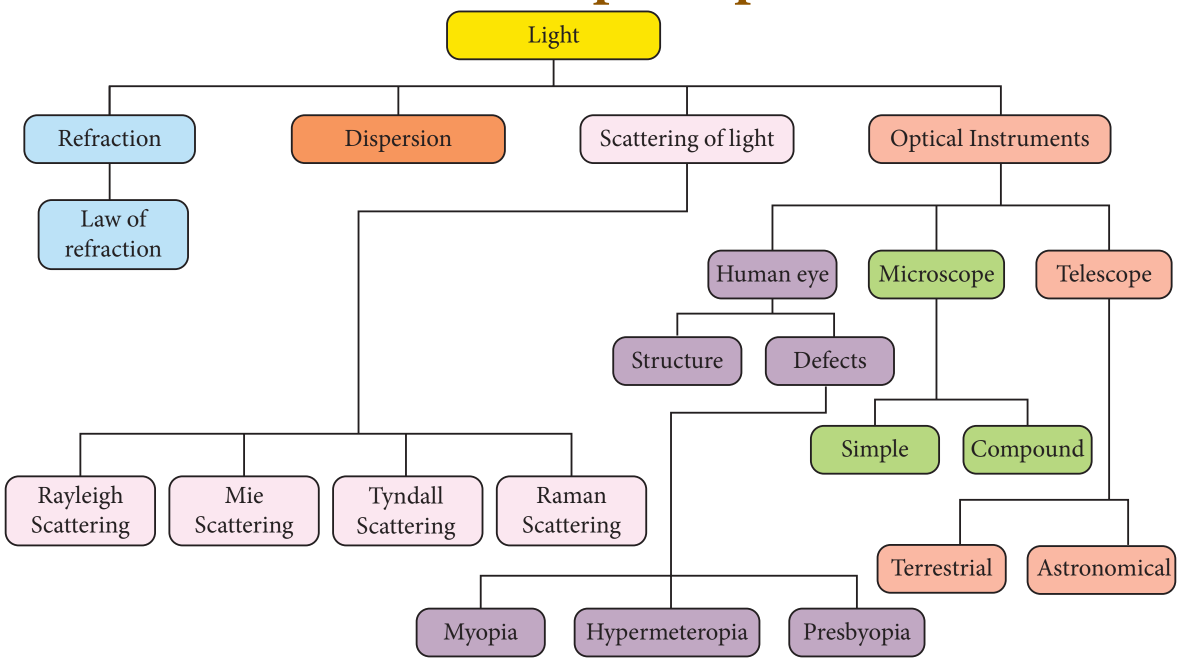
REFERENCE BOOKS

1. Fundamentals of optics by D.R. Khanna and H.R. Gulati, R. Chand & Co.
2. Principles of Physics – Halliday, Resnick & Walker, Wiley Publications, New Delhi.

INTERNET RESOURCES

1. www.physicsabout.com
2. www.khanacademy.org

Concept Map



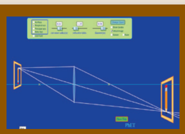
ICT CORNER

Formation of different types of images by a convex lens

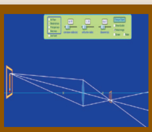
In this activity you will be able to understand the images formed by convex lenses.

Steps

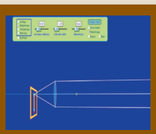
- Open the browser and type 'phet.colorado.edu/en/simulation/legacy/geometric-optics' in the address bar.
- Take the pencil and raise it so that the eraser is sitting on the principal axis. Click on the "principal rays" button.
- Place the object at different positions (infinity, beyond 2F, at 2F, between F and 2F, at F, between F and optic centre) from a convex lens and observe different types of images. Explain the result.
- Will the rays ever form an image? Click on "virtual image" to check your answer.



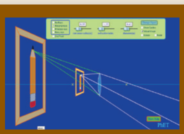
Step1



Step2



Step3



Step4

Cells alive

URL: https://phet.colorado.edu/en/simulation/legacy/geometric-optics

*Pictures are indicative only

B375_10_SCIENCE_EM

UNIT 3 THERMAL PHYSICS

Learning Objectives

6TEBIQ

At the end of this lesson, students will be able to

- Understand the concept of heat and temperature
- Know the absolute scale of temperature
- Understand the thermal energy and the thermal equilibrium
- Classification of expansion of substances
- Know the fundamental laws of gases
- Distinguish between real gas and ideal gas
- Derive the ideal gas equation
- Solve the numerical problems

INTRODUCTION

Sun is the primary source of thermal energy for all living organisms. Thermal energy is the cause and temperature is the effect. All living organisms need a particular temperature for their survival. In the kitchen, a container with a steel bottom is placed on the induction stove. Do you know why? All of us have a common man's understanding of thermal energy and temperature. But, in this chapter, you shall learn about thermal energy and temperature in a scientific manner. We shall also discuss about how thermal energy is transferred and the effects of thermal energy.

3.1 TEMPERATURE

Temperature is defined as the degree of hotness of a body. The temperature is higher for a hotter body than for a colder body. It is also be defined as the property which determines whether a body is in equilibrium or not with the surroundings. (or average kinetic enegy of the molecules). Further, temperature is the property, which determines the direction of flow of heat. It is a scalar quantity. The SI unit of temperature is kelvin (K). There are other commonly used units of temperature such as degree celsius (°C) and degree fahrenheit (°F).

3.1.1 Absolute scale (kelvin scale) of temperature

The temperature measured in relation to absolute zero using the kelvin scale is known as absolute temperature. It is also known as the **thermodynamic temperature.** Each unit of the thermodynamic scale of temperature is defined as the fraction of 1/273.16th part of the thermodynamic temperature of the triple point of water. A temperature difference of 1°C is equal to that of 1K. Zero Kelvin is the absolute scale of tempeture of the body.

The relation between the different types of scale of temperature:

Celsius and Kelvin: $K = C + 273$,

Fahrenheit and Kelvin: $[K] = (F + 460) \times \frac{5}{9}$

$0\,K = -273°C$.

3.1.2 Thermal equilibrium

Two or more physical systems or bodies are said to be in thermal equilibrium if there is no net flow of thermal energy between the systems. Heat energy always flows from one body to the other due to a temperature difference between them. Thus, you can define thermal equilibrium in another way. If two bodies are said to be in thermal equilibrium, then, they will be at the same temperature. What will happen if two bodies at different temperatures are brought in contact with one other? There will be a transfer of heat energy from the hot body to the cold body until a thermal equilibrium is established between them. This is depicted in Figure 3.1.

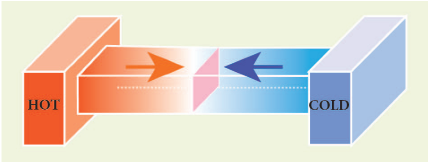


Figure 3.1 Establishing thermal equilibrium

When a cold body is placed in contact with a hot body, some thermal energy is transferred from the hot body to the cold body. As a result, there is some rise in the temperature of the cold body and decrease in the temperature of the hot body. This process will continue until these two bodies attain the same temperature.

3.2 THERMAL ENERGY

If you leave a cup of hot milk on a table for some time, what happens? The hotness of the milk decreases after some time. Similarly, if you keep a bottle of cold water on a table, the water becomes warmer after some time. What do you infer from these observations? In the case of hot milk, there is a flow of energy from the cup of milk to the environment. In the second case, the energy is transferred from the environment to the water bottle. This energy is termed as "thermal energy".

When a hot object is in contact with another cold object, a form of energy flows from the hot object to the cold object, which is known as **thermal energy**. Thus, thermal energy is a form of energy which is transferred between any two bodies due to the difference in their temperatures. Thermal energy is also known as 'heat energy' or simply 'heat'.

Heat energy is the agent, which produces the sensation of warmth and makes bodies hot. The process in which heat energy flows from a body at a higher temperature to another object at lower temperature is known as **heating**. This process of transmission of heat may be done in any of the ways like conduction, convection or radiation. Heat is a scalar quantity. The SI unit of heat energy absorbed or evolved is joule (J) .

During the process of transferring heat energy, the body at lower temperature is heated while the body at higher temperature is cooled. Thus, sometimes, this process of transfer of heat energy is termed as 'cooling'. But, in most of the cases the term 'heating' is used instead of 'cooling'. When the thermal energy is transferred from one body to another, this results in the rise or lowering of the temperature of either of the bodies.

3.2.1 Characteristic features of heat energy transfer

1. Heat always flows from a system at higher temperature to a system at lower temperature.
2. The mass of a system is not altered when it is heated or cooled.
3. For any exchange of heat, the heat gained by the cold system is equal to heat lost by the hot system. *Heat gained = Heat lost*

3.2.2 Other units of Heat energy

Though the SI unit of heat energy is joule, there are some other commonly used units.

Calorie: *One calorie is defined as the amount of heat energy required to rise the temperature of 1 gram of water through 1°C.*

Kilocalorie: *One kilocalorie is defined as the amount of heat energy required to rise the temperature of 1 kilogram of water through 1°C.*

3.3 EFFECT OF HEAT ENERGY

When a certain amount of heat energy is given to a substance, it will undergo one or more of the following changes:

- Temperature of the substance rises.
- The substance may change its state from solid to liquid or from liquid to gas.
- The substance will expand when heated.

The rise in temperature is in proportion to the amount of heat energy supplied. It also depends on the nature and mass of the substance. About the rise in temperature and the change of state, you have studied in previous classes. In the following section, we shall discuss about the expansion of substances due to heat.

3.3.1 Expansion of Substances

When heat energy is supplied to a body, there can be an increase in the dimension of the object. This change in the dimension due to rise in temperature is called thermal expansion of the object. The expansion of liquids (e.g. mercury) can be seen when a thermometer is placed in warm water. All forms of matter (solid, liquid and gas) undergo expansion on heating.

a) Expansion in solids

When a solid is heated, the atoms gain energy and vibrate more vigorously. This results in the expansion of the solid. For a given change in temperature, the extent of expansion is smaller in solids than in liquids and gases. This is due to the rigid nature of solids.

The different types of expansion of solid are listed and explained below:

1. Linear expansion
2. Superficial expansion
3. Cubical expansion

1. Linear expansion:

When a body is heated or cooled, the length of the body changes due to change in its temperature. Then the expansion is said to be **linear or longitudinal expansion**.

The ratio of increase in length of the body per degree rise in temperature to its unit length is called as the **coefficient of linear expansion**. The SI unit of Coefficient of Linear expansion is K^{-1}. The value of coefficient of linear expansion is different for different materials.

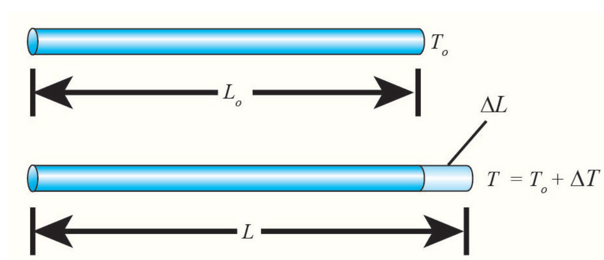


Figure 3.2 Linear expansion

The equation relating the change in length and the change in temperature of a body is given below:

$$\frac{\Delta L}{L_o} = \alpha_L \Delta T$$

ΔL - Change in length (Final length- Original length)

L_o - Original length

ΔT - Change in temperature (Final temperature - Initial temperature)

α_L - Coefficient of linear expansion.

2. Superficial expansion:

If there is an increase in the area of a solid object due to heating, then the expansion is called **superficial or areal expansion.**

Superficial expansion is determined in terms of coefficient of superficial expansion. The ratio of increase in area of the body per degree rise in temperature to its unit area is called as **coefficient of superficial expansion**. Coefficient of superficial expansion is different for different materials. The SI unit of Coefficient of superficial expansion is K^{-1}

The equation relating to the changein area and the change in temperature is given below:

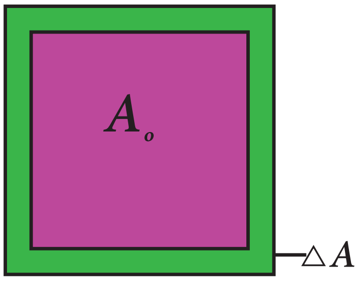


Figure 3.3 Superficial expansion

$$\frac{\Delta A}{A_o} = \alpha_A \Delta T$$

ΔA - Change in area (Final area - Initial area)

A_o - Original area

ΔT - Change in temperature (Final temperature - Initial temperature)

α_A - Coefficient of superficial expansion.

3. Cubical expansion:

If there is an increase in the volume of a solid body due to heating, then the expansion is called **cubical or volumetric expansion.**

As in the cases of linear and areal expansion, cubical expansion is also expressed in terms of coefficient of cubical expansion. The ratio of increase in volume of the body per degree rise in temperature to its unit volume is called as **coefficient of cubical expansion**. This is also measured in K^{-1}.

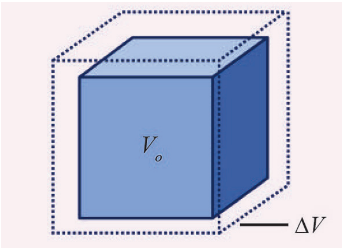


Figure 3.4 Cubical expansion

The equation relating to the change in volume and the change in temperature is given below:

$$\frac{\Delta V}{V_o} = \alpha_V \Delta T$$

ΔV - Change in volume(Final volume - Intial volume)

V_o - Original volume

ΔT - Change in temperature (Final temperature - Initial temperature)

α_V - Coefficient of cubical expansion.

Different materials possess different coefficient of cubical expansion. Table 3.1 gives the coefficient of cubical expansion for some common materials.

Table 3.1 Coefficient of cubical expansion of some materials

S.No.	Name of the material	Coefficient of cubic expansion (K^{-1})
1	Aluminium	7×10^{-5}
2	Brass	6×10^{-5}
3	Glass	2.5×10^{-5}
4	Water	20.7×10^{-5}
5	Mercury	18.2×10^{-5}

b) Expansion in liquids and gases

When heated, the atoms in a liquid or gas gain energy and are forced further apart. The extent of expansion varies from substance to substance. For a given rise in temperature, a liquid will have more expansion than a solid and a gaseous substance has the highest expansion when compared with the other two. The coefficient of cubical expansion of liquid is independent of temperature whereas its value for gases depends on the temperature of gases.

When a liquid is heated, it is done by keeping the liquid in some container and supplying heat energy to the liquid through the container. The thermal energy supplied will be partly used in expanding the container and partly used in expanding the liquid. Thus, what we observe may not be the actual or real expansion of the liquid. Hence, for liquids, we can define real expansion and apparent expansion.

1) Real expansion

If a liquid is heated directly without using any container, then the expansion that you observe is termed as **real expansion** of the liquid.

Coefficient of real expansion is defined as the ratio of the true rise in the volume of the liquid per degree rise in temperature to its unit volume. The SI unit of coefficient of real expansion is K^{-1}.

2) Apparent expansion

Heating a liquid without using a container is not possible. Thus, in practice, you can heat any liquid by pouring it in a container. A part of thermal energy is used in expanding the container and a part is used in expanding the liquid. Thus, what you observe is not the actual or real expansion of the liquid. The expansion of a liquid apparently observed without considering the expansion of the container is called the **apparent expansion** of the liquid.

Coefficient of apparent expansion is defined as the ratio of the apparent rise in the volume of the liquid per degree rise in temperature to its unit volume. The SI unit of coefficient of apparent expansion is K^{-1}.

3.3.2 Experiment to measure real and apparent expansion of liquid

To start with, the liquid whose real and apparent expansion is to be determined is poured in a container up to a level. Mark this level as L_1. Now, heat the container and the liquid using a burner as shown in the Figure 3.5.

Initially, the container receives the thermal energy and it expands. As a result, the volume of the liquid appears to have reduced. Mark this reduced level of liquid as L_2.

On further heating, the thermal energy supplied to the liquid through the container results in the expansion of the liquid. Hence, the level of liquid rises to L_3. Now, the difference between the levels L_1 and L_3 is called as **apparent expansion,** and the difference between the levels L_2 and L_3 is called **real expansion**. The real expansion is always more than that of apparent expansion.

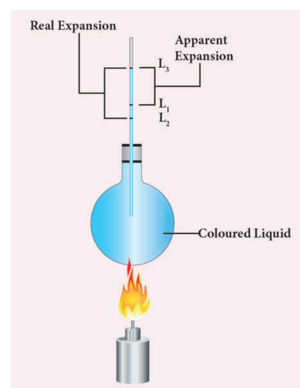


Figure 3.5 Real and apparent expansion of liquid

Real expansion = $L_3 - L_2$

Apparent expansion = $L_3 - L_1$

3.4 FUNDAMENTAL LAWS OF GASES

The three fundamental laws which connect the relation between pressure, volume and temperature are as follows:

1) Boyle's Law
2) Charles's law
3) Avogadro's law

3.4.1 Boyle's law:

When the temperature of a gas is kept constant, the volume of a fixed mass of gas is inversely proportional to its pressure. This is shown in Figure 3.6.

$$P \propto 1/V$$

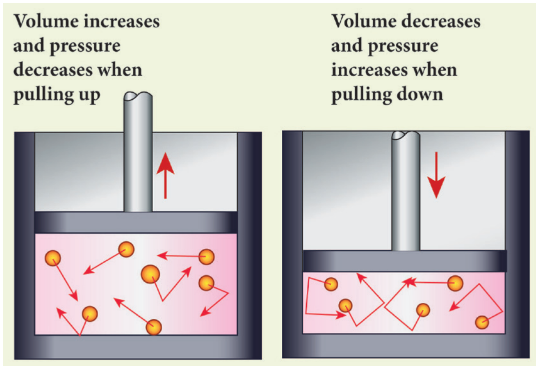


Figure 3.6 Variation of volume with pressure

In other words, for an invariable mass of a perfect gas, at constant temperature, the product of its pressure and volume is a constant.

(i.e) PV = constant

3.4.2 Charles's law (The law of volume)

Charles's law was formulated by a French scientist Jacques Charles. According to this law, *When the pressure of gas is kept constant, the volume of a gas is directly proportional to the temperature of the gas.*

$$V \propto T$$

$$\text{or } \frac{V}{T} = \text{constant}$$

3.4.3 Avogadro's law

Avogadro's law states that at constant pressure and temperature, the volume of a gas is directly proportional to number of atoms or molecules present in it.

8I8UMD

$$\text{i.e.} \quad V \propto n$$

$$\text{(or)} \quad \frac{V}{n} = \text{constant}$$

Avogadro's number (N_A) is the total number of atoms per mole of the substance. It is equal to 6.023×10^{23} /mol.

3.5 GASES

Gases are classified as real gases and ideal gases.

3.5.1 Real Gases

If the molecules or atoms of a gases interact with each other with a definite amount of intermolecular or inter atomic force of attraction, then the gases are said to be **real gases.** At very high temperature or low pressure, a real gases behaves as an ideal gases because in this condition there is no interatomic or intermolecular force of attraction.

3.5.2 Ideal Gases

If the atoms or molecules of a gas do not interact with each other, then the gas is said to be an **ideal gas** or a **perfect gas.**

Actually, in practice, no gas is ideal. The molecules of any gas will have a certain amount of interaction among them. But, these interactions are weaker when the pressure is low or the temperature is high because the interatomic or intermolecular forces of attraction are weak in ideal gas. Hence, a real gas at low pressure or high temperature can be termed as a perfect gas.

Ideal gases obey Boyle's law, Charles's law and Avogadro's law. All these laws state the relationship between various properties of a gas such as pressure (P), volume (V), temperature (T) and number of atoms (n). In a given state of the gas, all these parameters will have a definite set of values. When there is a change in the state of the gas, any one or more of these parameters change its value. The above said laws relate these changes.

3.5.3 Ideal Gas Equation

The ideal gas equation is an equation, which relates all the properties of an ideal gas. An ideal gas obeys Boyle's law and Charles' law and Avogadro's law. According to Boyle's law,

$$PV = constant \qquad (3.1)$$

According to Charles's law,

$$V/T = constant \quad (3.2)$$

According to Avogadro's law,

$$V/n = constant \quad (3.3)$$

After combining equations (3.1), (3.2) and (3.3), you can get the following equation.

$$PV/nT = constant \quad (3.4)$$

The above relation is called the combined law of gases. If you consider a gas, which contains μ moles of the gas, the number of atoms contained will be equal to μ times the Avogadro number, N_A.

$$i.e. \quad n = \mu N_A. \quad (3.5)$$

Using equation (3.5), equation (3.4) can be written as

$$PV/\mu N_A T = constant$$

The value of the constant in the above equation is taken to be k_B, which is called as **Boltzmann constant (1.38×10^{-23} JK^{-1}).** Hence, we have the following equation:

$$PV/\mu N_A T = k_B$$

$$PV = \mu N_A k_B T$$

Here, $\mu N_A k_B = R$, which is termed as universal gas constant whose value is

$8.31\ J\ mol^{-1} K^{-1}$.

$$PV = RT \quad (3.6)$$

Ideal gas equation is also called as *equation of state* because it gives the relation between the state variables and it is used to describe the state of any gas.

Points to Remember

- The SI unit of heat energy absorbed or evolved is joule (J)
- Heat always flows from a system at higher temperature to a system at lower temperature.
- **Temperature** is defined as the degree of hotness of a body. The SI unit of temperature is kelvin (K).
- All the substances will undergo one or more of the following changes when heated:
  - i) Temperature of the substance rises.
  - ii) The substance may change state from solid to liquid or gas.
  - iii) The substance will expand when heated.
- All forms of matter (solid, liquid and gas) undergo expansion on heating.
- For a given rise in temperature, a liquid will have more expansion than a solid and a gaseous substance has the highest expansion than the other two.
- If a liquid is heated directly without using any container, then the expansion that you observe is termed as **real expansion** of the liquid.
- The expansion of a liquid apparently observed without considering the expansion of the container is called the **apparent expansion** of liquid.
- For a given heat energy, the real expansion is always more than that of apparent expansion.
- If the atoms or molecules of a gas do not interact with each other, then the gas is said to be an **ideal gas** or a **perfect gas**.
- Ideal gas equation, also called as equation of state is PV = RT. Here, R is known as universal gas constant whose value is $8.31\ J\ mol^{-1}K^{-1}$

Solved Problems

Example 1

A container whose capacity is 70 ml is filled with a liquid up to 50 ml. Then, the liquid in the container is heated. Initially, the level of the liquid falls from 50 ml to 48.5 ml. Then we heat more, the level of the liquid rises to 51.2 ml. Find the apparent and real expansion.

Data:

Level of the liquid L_1 = 50 ml

Level of the liquid L_2 = 48.5 ml

Level of the liquid L_3 = 51.2 ml

Apparent expansion $= L_3 - L_1$

$= 51.2\,\text{ml} - 50\,\text{ml} = 1.2\text{ml}$

Real expansion $= L_3 - L_1$

$= 51.2\text{ ml} - 48.5\text{ml} = 2.7\text{ml}$

So, Real expansion > apparent expansion

Example 2

Keeping the temperature as constant, a gas is compressed four times of its initial pressure. The volume of gas in the container changing from 20cc (V_1 cc) to V_2 cc. Find the final volume V_2.

Data:

Initial pressure (P_1)= P

Final Pressure (P_2) = 4P

Initial volume (V_1) = 20cc = 20cm³

Final volume (V_2) = ?

Using Boyle's Law, PV = constant

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1}{P_2} \times V_1$$

$$= \frac{P}{4P} \times 20\text{cm}^3$$

$$V_2 = 5\text{ cm}^3$$

TEXTBOOK EVALUATION

I. Choose the correct answer

1. The value of universal gas constant

a) 3.81 $\text{mol}^{-1}\text{ K}^{-1}$ b) 8.03 $\text{mol}^{-1}\text{ K}^{-1}$

c) 1.38 $\text{mol}^{-1}\text{ K}^{-1}$ d) 8.31 $\text{mol}^{-1}\text{ K}^{-1}$

2. If a substance is heated or cooled, the change in mass of that substance is

a) positive b) negative

c) zero d) none of the above

3. If a substance is heated or cooled, the linear expansion occurs along the axis of

a) X or −X b) Y or −Y

c) both (a) and (b) d) (a) or (b)

4. Temperature is the average ___________ of the molecules of a substance

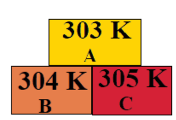
a) difference in K.E and P.E

b) sum of P.E and K.E

c) difference in T.E and P.E

d) difference in K.E and T.E

5. In the Given diagram, the possible direction of heat energy transformation is



a) $A \leftarrow B,\ A \leftarrow C,\ B \leftarrow C$

b) $A \rightarrow B,\ A \rightarrow C,\ B \rightarrow C$

c) $A \rightarrow B,\ A \leftarrow C,\ B \rightarrow C$

d) $A \leftarrow B,\ A \rightarrow C,\ B \leftarrow C$

II. Fill in the blanks:

1. The value of Avogadro number _________

2. The temperature and heat are __________ quantities

3. One calorie is the amount of heat energy required to raise the temperature of ________ of water through_______.

4. According to Boyle's law, the shape of the graph between pressure and reciprocal of volume is _______________

III. State whether the following statements are true or false, if false explain why?

1. For a given heat in liquid, the apparent expansion is more than that of real expansion.

10th_Science_Unit-3.indd 39 21-02-2019 18:35:35

2. Thermal energy always flows from a system at higher temperature to a system at lower temperature.
3. According to Charles's law, at constant pressure, the temperature is inversely proportional to volume.

IV. Match the items in column-I to the items in column-II

Column-I	Column-II
1. Linear expansion	- (a) change in volume
2. Superficial expansion	- (b) hot body to cold body
3. Cubical expansion	- (c) 1.381 X 10^{-23} JK^{-1}
4. Heat transformation	- (d) change in length
5. Boltzmann constant	- (e) change in area

V. Assertion and reason type questions

a. Both the assertion and the reason are true and the reason is the correct explanation of the assertion.

b. Both the assertion and the reason are true but the reason is not the correct explanation of the assertion.

c. Assertion is true but the reason is false.

d. Assertion is false but the reason is true.

1. **Assertion:** There is no effects on other end when one end of the rod is only heated.

   Reason: Heat always flows from a region of lower temperature to higher temperature of the rod.

2. **Assertion:** Gas is highly compressible than solid and liquid

   Reason: Interatomic or intermolecular distance in the gas is comparably high.

VI. Answer in briefly

1. Define one calorie.
2. Distinguish between linear, arial and superficial expansion.
3. What is co-efficient of cubical expansion?
4. State Boyle's law
5. State-the law of volume
6. Distinguish between ideal gas and real gas.
7. What is co-efficient of real expansion?
8. What is co-efficient of apparent expansion?

VII. Numerical problems

1. Find the final temperature of a copper rod. Whose area of cross section changes from $10\,m^2$ to $11\,m^2$ due to heating. The copper rod is initially kept at 90 K. (Coefficient of superficial expansion is 0.0021 /K)
2. Calculate the coefficient of cubical expansion of a zinc bar. Whose volume is increased $0.25\,m^3$ from $0.3\,m^3$ due to the change in its temperature of 50 K.

VIII. Answer in detail

1. Derive the ideal gas equation.
2. Explain the experiment of measuring the real and apparent expansion of a liquid with a neat diagram.

IX. HOT question

If you keep ice at 0° C and water at 0° C in either of your hands, in which hand you will feel more chillness? Why?

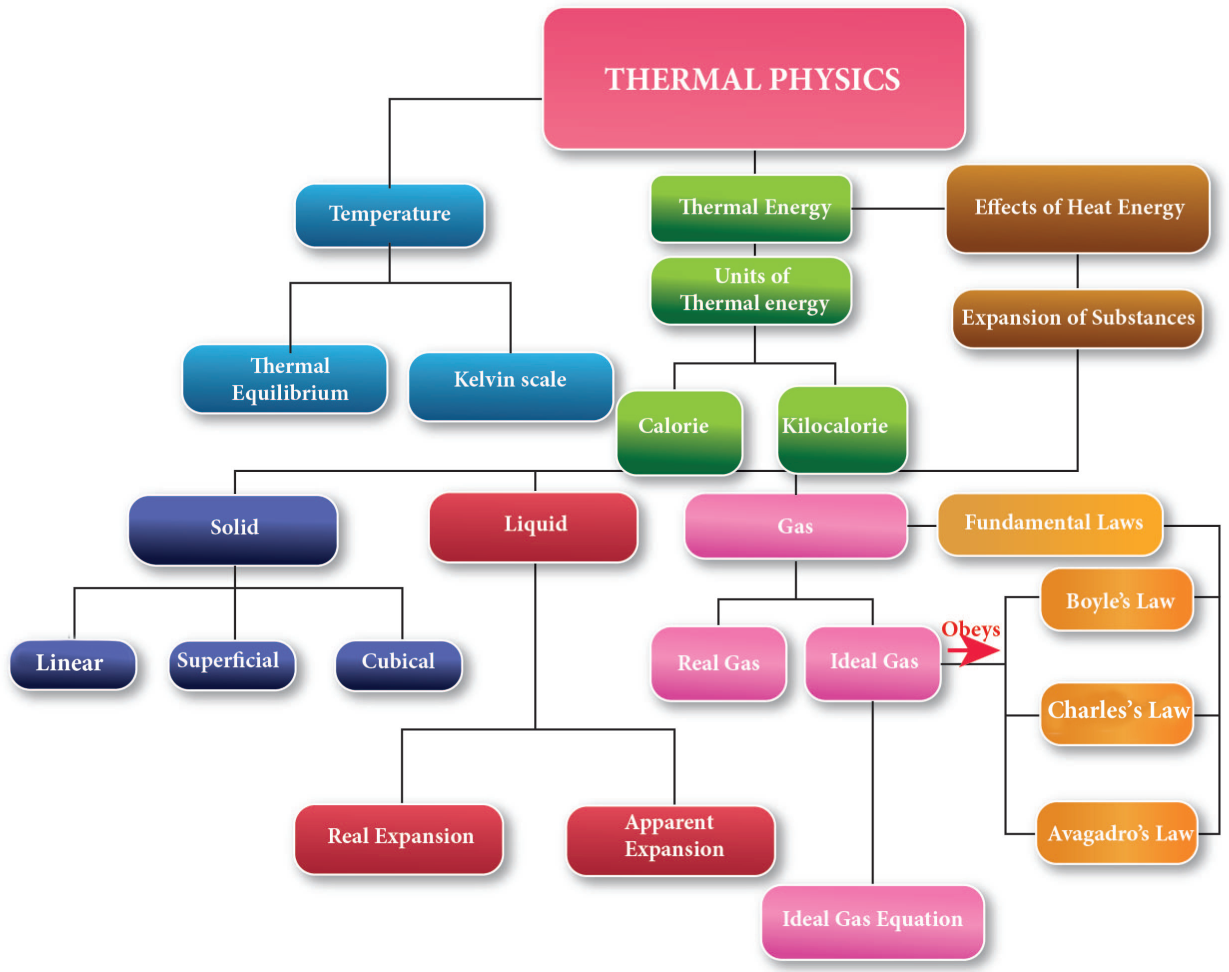
REFERENCE BOOKS

- Thermodynamics and an introduction to thermo statistics by Herbert Hallen
- Fundamentals of Engineering Thermodynamics by Michael Moran.

INTERNET RESOURCE

http://aplusphysics.com/courses/honors/thermo/thermal_physics.html

CONCEPT MAP



ICT CORNER

Boyle's law

In this activity you will be able to verify pressure is proportional to reciprocal of volume (Boyle's law).

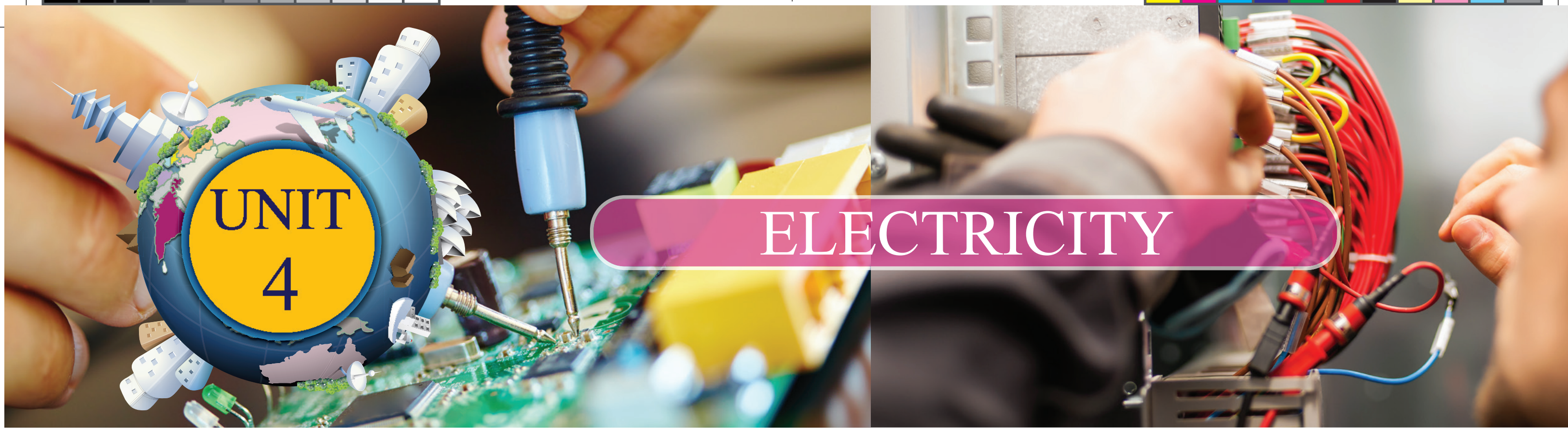
Steps

- Open the browser and type "physics-chemistry-interactive-flash-animation.com/matter_change_state_measurement_mass_volume/pressure_volume_boyle_mariotte_law_ideal_gas_closed_system_MCQ.htm" in the address bar. Click enter to start the experiment.
- Change the volume by adjusting the piston of the syringe (between 20 ml to 80 ml) and observe how the pressure changes.
- Tabulate observed values. You will observe when volume decreases pressure inside the syringe gets increased and vice versa. Thus boyle's law (PV = constant) verified.

Cells alive

URL: http://www.physics-chemistry-interactive-flash-animation.com/matter_change_state_measurement_mass_volume/pressure_volume_boyle_mariotte_law_ideal_gas_closed_system_MCQ.htm

B375_10_SCIENCE_EM



UNIT 4
ELECTRICITY

9DAJQ1

Learning Objectives

At the end of this lesson, students will be able to:

- Make an electric circuit.
- Differentiate between electric potential and potential difference.
- Infer what electrical resistivity and conductivity mean.
- Know the effective resistance of a system of resistors connected in series and parallel.
- Understand the heating effect of the electric current.
- Define electric power and electric energy and explain domestic electric circuits.
- Know the modern appliances such as LED bulb and LED television.

INTRODUCTION

You have already learnt about electricity in your lower classes, haven't you? Well, electricity deals with the flow of electric charges through a conductor. As a common term it refers to a form of energy. The usage of electric current in our day to day life is very important and indispensable. You are already aware of the fact that it is used in houses, educational institutions, hospitals, industries, etc. Therefore, its generation and transmission becomes a very crucial aspect of our life. In this lesson you will learn various terms used in understanding the concept of electricity. Eventually, you will realise the importance of the applications of electricity in day to day situations.

4.1 ELECTRIC CURRENT

The motion of electric charges (electrons) through a conductor (e.g., copper wire) will constitute an electric current. This is similar to the flow of water through a channel or flow of air from a region of high pressure to a region of low pressure.

In a similar manner, the electric current passes from the positive terminal (higher electric potential) of a battery to the negative terminal (lower electric potential) through a wire as shown in the Figure 4.1.

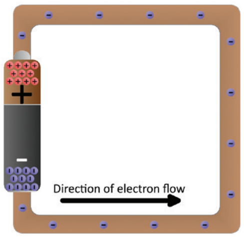


Figure 4.1
Electron flow

4.1.1 Definition of electric current

Electric current is often termed as 'current' and it is represented by the symbol 'I'. It is defined **as the rate of flow of charges in a conductor**. This means that the electric current represents the amount of charges flowing in any cross section of a conductor (say a metal wire) in unit time. If a net charge 'Q' passes through any cross section of a conductor in time ‘t’, then the current flowing through the conductor is

$$I = \frac{Q}{t} \qquad (4.1)$$

4.1.2 SI unit of electric current

The SI unit of electric current is ampere (A). The current flowing through a conductor is said to be one ampere, when a charge of one coulomb flows across any cross-section of a conductor, in one second. Hence,

$$1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}.$$

Solved Problem-1

A charge of 12 coulomb flows through a bulb in 5 second. What is the current through the bulb?

Solution:

Charge Q = 12 C, Time t = 5 s. Therefore,

current $I = \frac{Q}{t} = \frac{12}{5} = 2.4$ A

4.2 ELECTRIC CIRCUIT

An electric circuit is a closed conducting loop (or) path, which has a network of electrical components through which electrons are able to flow. This path is made using electrical wires so as to connect an electric appliance to a source of electric charges (battery). A schematic diagram of an electric circuit comprising of a battery, an electric bulb, and a switch is given in Figure 4.2.

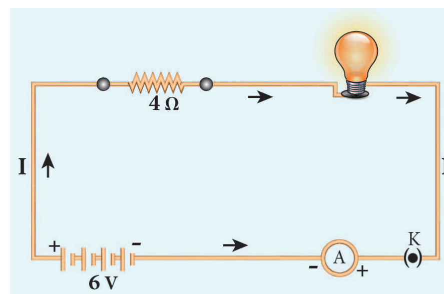
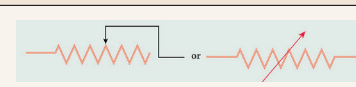
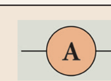
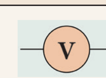
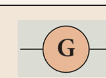
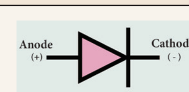
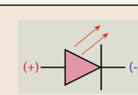
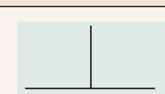


Figure 4.2 A simple electric circuit

Table 4.1 Symbols of some components of a circuit

COMPONENT	USE OF THE COMPONENT	SYMBOL USED
Resistor	Used to fix the magnitude of the current through a circuit	
Variable resistor or Rheostat	Used to select the magnitude of the current through a circuit.	
Ammeter	Used to measure the current.	
Voltmeter	Used to measure the potential difference.	
Galvanometer	Used to indicate the direction of current.	
A diode	A diode has various uses, which you will study in higher classes.	
Light Emitting Diode (LED)	A LED has various uses which you will study in higher classes.	
Ground connection	Used to provide protection to the electrical components. It also serves as a reference point to measure the electric potential.	

In this circuit, if the switch is 'on', the bulb glows. If it is switched off, the bulb does not glow. Therefore, the circuit must be closed in order that the current passes through it. The potential difference required for the flow of charges is provided by the battery. The electrons flow from the negative terminal to the positive terminal of the battery.

By convention, the direction of current is taken as the direction of flow of positive charge (or) opposite to the direction of flow of electrons. Thus, electric current passes in the circuit from the positive terminal to the negative terminal.

4.2.1 Electrical components

The electric circuit given in Figure 4.2 consists of different components, such as a battery, a switch and a bulb. All these components can be represented by using certain symbols. It is easier to represent the components of a circuit using their respective symbols.

The symbols that are used to represent some commonly used components are given in Table 4.1. The uses of these components are also summarized in the table.

4.3 ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE

You are now familiar with the water current and air current. You also know that there must be a difference in temperature between two points in a solid for the heat to flow in it. Similarly, a difference in electric potential is needed for the flow of electric charges in a conductor. In the conductor, the charges will flow from a point in it, which is at a higher electric potential to a point, which is at a lower electric potential.

4.3.1 Electric Potential

The electric potential at a point is defined as the amount of work done in moving a unit positive charge from infinity to that point against the electric force.

4.3.2 Electric Potential Difference

The electric potential difference between two points is defined as the amount of work done in moving a unit positive charge from one point to another point against the electric force.

Figure 4.3 Electric potential

Suppose, you have moved a charge Q from a point A to another point B. Let 'W' be the work done to move the charge from A to B. Then, the potential difference between the points A and B is given by the following expression:

$$\text{Potential Difference (V)} = \frac{\text{Work Done (W)}}{\text{Charge (Q)}} \qquad (4.2)$$

Potential difference is also equal to the difference in the electric potential of these two points. If V_A and V_B represent the electric potential at the points A and B respectively, then, the potential difference between the points A and B is given by:

$V = V_A - V_B$ (if V_A is more than V_B)

$V = V_B - V_A$ (if V_B is more than V_A)

4.3.3 Volt

The SI unit of electric potential or potential difference is volt (V).

The potential difference between two points is one volt, if one joule of work is done in moving one coulomb of charge from one point to another against the electric force.

$$1\,\text{volt} = \frac{1\ \text{joule}}{1\ \text{coulomb}}$$

Solved Problem-2

The work done in moving a charge of 10 C across two points in a circuit is 100 J. What is the potential difference between the points?

Solution:

Charge, Q = 10 C Work Done, W = 100 J

Potential Difference $V = \frac{W}{Q} = \frac{100}{10}$.

Therefore, V = 10 volt

4.4 OHM'S LAW

A German physicist, Georg Simon Ohm established the relation between the potential difference and current, which is known as Ohm's Law. This relationship can be understood from the following activity.

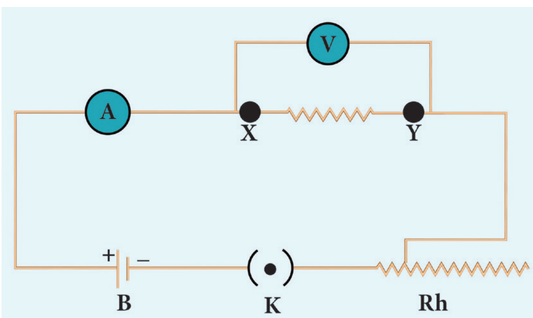


Figure 4.4 Electric circuit to understand Ohm's law

According to Ohm's law, at a constant temperature, the steady current 'I' flowing through a conductor is directly proportional to the potential difference 'V' between the two ends of the conductor.

$I \propto V$. Hence, $\frac{I}{V}$ = constant.

The value of this proportionality constant is found to be $\frac{1}{R}$

Therefore, $I = \left(\frac{1}{R}\right) V$

$$V = I\,R \qquad (4.3)$$

Here, R is a constant for a given material (say Nichrome) at a given temperature and is known as the **resistance** of the material. Since, the potential difference V is proportional to the current I, the graph between V and I is a straight line for a conductor, as shown in the Figure 4.5.

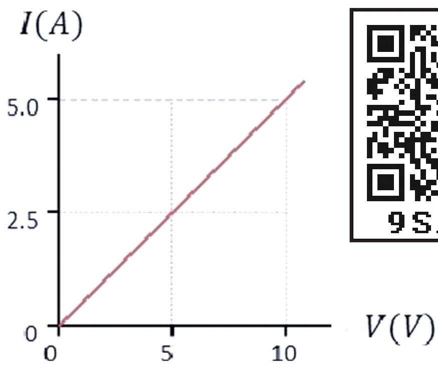


Figure 4.5 Relation between potential difference and current

4.5 RESISTANCE OF A MATERIAL

In Figure 4.4, a Nichrome wire was connected between X and Y. If you replace the Nichrome wire with a copper wire and conduct the same experiment, you will notice a different current for the same value of the potential difference across the wire. If you again replace the copper wire with an aluminium wire, you will get another value for the current passing through it. From equation (4.3), you have learnt that V/I must be equal to the resistance of the conductor used. The variations in the current for the same values of potential difference indicate that the resistance of different materials is different. Now, the primary question is, "what is resistance?"

Resistance of a material is its property to oppose the flow of charges and hence the passage of current through it. ***It is different for different materials***.

From Ohm's Law, $\frac{V}{I} = R$.

The resistance of a conductor can be defined as the ratio between the potential difference across the ends of the conductor and the current flowing through it.

4.5.1 Unit of Resistance

The SI unit of resistance is ohm and it is represented by the symbol Ω.

Resistance of a conductor is said to be one ohm if a current of one ampere flows through it when a potential difference of one volt is maintained across its ends.

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

Solved Problem-3

Calculate the resistance of a conductor through which a current of 2 A passes, when the potential difference between its ends is 30 V.

Solution:

Current through the conductor I = 2 A, Potential Difference V = 30 V

From Ohm's Law: $R = \frac{V}{I}$.

Therefore, $R = \frac{30}{2} = 15\ \Omega$

4.6 ELECTRICAL RESISTIVITY & ELECTRICAL CONDUCTIVITY

4.6.1 Electrical Resistivity

You can verify by doing an experiment that the resistance of any conductor 'R' is directly proportional to the length of the conductor 'L' and is inversely proportional to its area of cross section 'A'.

$$R \propto L,\ R \propto \frac{1}{A},$$

$$\text{Hence},\ R \propto \frac{L}{A}$$

Therefore, $R = \rho \frac{L}{A}$ (4.4)

Where, ρ (rho) is a constant, called as electrical resistivity or specific resistance of the material of the conductor.

From equation (4.4), $\rho = \frac{RA}{L}$

If L = 1 m, A = 1 m^2 then, from the above equation $\rho = R$

Hence, the electrical resistivity of a material is ***defined as the resistance of a conductor of unit length and unit area of cross section***. Its unit is **ohm metre**.

Electrical resistivity of a conductor is a measure of the resisting power of a specified material to the passage of an electric current. It is a constant for a given material.

DO YOU KNOW?

Nichrome is a conductor with highest resistivity equal to $1.5 \times 10^{-6}\ \Omega$ m. Hence, it is used in making heating elements.

4.6.2 Conductance and Conductivity

Conductance of a material is the property of a material to aid the flow of charges and hence, the passage of current in it. The conductance of a material is mathematically ***defined as the reciprocal of its resistance*** (R). Hence, the conductance '**G**' of a conductor is given by

$$G = \frac{1}{R} \quad (4.5)$$

Its unit is ohm^{-1}. It is also represented as 'mho'.

The reciprocal of electrical resistivity of a material is called its electrical conductivity.

$$\sigma = \frac{1}{\rho} \quad (4.6)$$

Its unit is ohm^{-1} metre^{-1}. It is also represented as mho metre^{-1}. The conductivity is a constant for a given material. Electrical conductivity of a conductor is a measure of its ability to pass the current through it. Some materials are good conductors of electric current. Example: copper, aluminium, etc. While some other materials are non-conductors of electric current (insulators). Example: glass, wood, rubber, etc.

Conductivity is more for conductors than for insulators. But, the resistivity is less for conductors than for insulators. The resistivity of some commonly used materials is given in Table 4.2.

Table 4.2 Resistivity of some materials

NATURE OF THE MATERIAL	MATERIAL	RESISTIVITY (Ω m)
Conductor	Copper	1.62×10^{-8}
	Nickel	6.84×10^{-8}
	Chromium	12.9×10^{-8}
Insulator	Glass	10^{10} to 10^{14}
	Rubber	10^{13} to 10^{16}

Solved Problem-4

The resistance of a wire of length 10 m is 2 ohm. If the area of cross section of the wire is 2×10^{-7} m^2, determine its (i) resistivity (ii) conductance and (iii) conductivity

Solution:

Given: Length, L = 10 m, Resistance, R = 2 ohm and Area, A = 2×10^{-7} m^2

$$\text{Resistivity, } \rho = \frac{RA}{L} = \frac{2 \times 2 \times 10^{-7}}{10}$$

$$= 4 \times 10^{-8}\ \Omega\text{ m}$$

$$\text{Conductance, } \mathbf{G} = \frac{1}{R} = \frac{1}{2} = 0.5 \text{ mho}$$

$$\text{Conductivity, } \sigma = \frac{1}{\rho} = \frac{1}{4 \times 10^{-8}}$$

$$= 0.25 \times 10^{-8} \text{ mho m}^{-1}$$

4.7 SYSTEM OF RESISTORS

So far, you have learnt how the resistance of a conductor affects the current through a circuit. You have also studied the case of the simple electric circuit containing a single resistor. Now in practice, you may encounter a complicated circuit, which uses a combination of many resistors. This combination of resistors is known as 'system of resistors' or 'grouping of resistors'. Resistors can be connected in various combinations. The two basic methods of joining resistors together are:

a) Resistors connected in series, and b) Resistors connected in parallel.

In the following sections, you shall compute the effective resistance when many resistors having different resistance values are connected in series and in parallel.

4.7.1 Resistors in series

A series circuit connects the components one after the other to form a 'single loop'. A series circuit has only one loop through which current can pass. If the circuit is interrupted at any point in the loop, no current can pass through the circuit and hence no electric appliances connected in the circuit will work. Series circuits are commonly used in devices such as flashlights. ***Thus, if resistors are connected end to end, so that the same current passes through each of them, then they are said to be connected in series.***

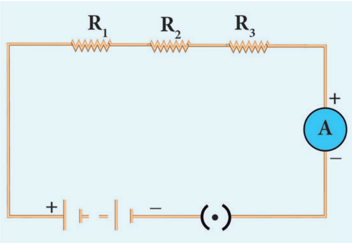


Figure 4.6 Series connection of resistors

Let, three resistances R_1, R_2 and R_3 be connected in series (Figure 4.6). Let the current flowing through them be I. According to Ohm's Law, the potential differences V_1, V_2 and V_3 across R_1, R_2 and R_3 respectively, are given by:

$$V_1 = I R_1 \qquad (4.7)$$

$$V_2 = I R_2 \qquad (4.8)$$

$$V_3 = I R_3 \qquad (4.9)$$

The sum of the potential differences across the ends of each resistor is given by:

$$V = V_1 + V_2 + V_3$$

Using equations (4.7), (4.8) and (4.9), we get

$$V = I R_1 + I R_2 + I R_3 \qquad (4.10)$$

The effective resistor is a single resistor, which can replace the resistors effectively, so as to allow the same current through the electric circuit. Let, the effective resistance of the series-combination of the resistors, be R_S. Then,

$$V = I R_S \qquad (4.11)$$

Combining equations (4.10) and (4.11), you get,

$$I R_S = I R_1 + I R_2 + I R_3$$

$$R_S = R_1 + R_2 + R_3 \qquad (4.12)$$

Thus, you can understand that when a number of resistors are connected in series, their equivalent resistance or effective resistance is equal to the sum of the individual resistances. When 'n' resistors of equal resistance R are connected in series, the equivalent resistance is 'n R'.

i.e., $R_S = n R$

The equivalent resistance in a series combination is greater than the highest of the individual resistances.

Solved Problem-5

Three resistors of resistances 5 ohm, 3 ohm and 2 ohm are connected in series with 10 V battery. Calculate their effective resistance and the current flowing through the circuit.

Solution:

$R_1 = 5\ \Omega$, $R_2 = 3\ \Omega$, $R_3 = 2\ \Omega$, $V = 10$ V

$R_s = R_1 + R_2 + R_3$, $R_s = 5 + 3 + 2 = 10$, hence $R_s = 10\ \Omega$

The current, $I = \frac{V}{R_S} = \frac{10}{10} = 1$ A

4.7.2 Resistances in Parallel

A parallel circuit has two or more loops through which current can pass. If the circuit is disconnected in one of the loops, the current can still pass through the other loop(s). The wiring in a house consists of parallel circuits.

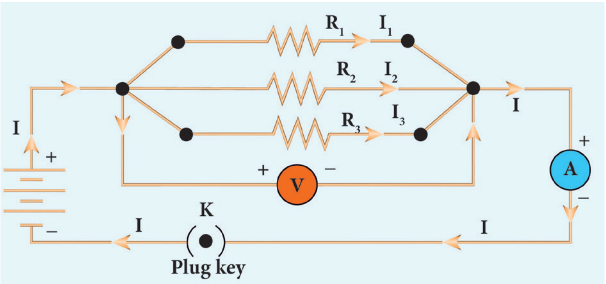


Figure 4.7 Parallel connections of resistors

Consider that three resistors R_1, R_2 and R_3 are connected across two common points A and B. The potential difference across each resistance is the same and equal to the potential difference between A and B. This is measured using the voltmeter. The current I arriving at A divides into three branches I_1, I_2 and I_3 passing through R_1, R_2 and R_3 respectively.

According to the Ohm's law, you have,

$$I_1 = \frac{V}{R_1} \qquad (4.13)$$

$$I_2 = \frac{V}{R_2} \qquad (4.14)$$

$$I_3 = \frac{V}{R_3} \qquad (4.15)$$

The total current through the circuit is given by

$$I = I_1 + I_2 + I_3$$

Using equations (4.13), (4.14) and (4.15), you get

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \qquad (4.16)$$

Let the effective resistance of the parallel combination of resistors be R_P. Then,

$$I = \frac{V}{R_P} \qquad (4.17)$$

Combining equations (4.16) and (4.17), you have

$$\frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad (4.18)$$

Thus, when a number of resistors are connected in parallel, the sum of the reciprocals of the individual resistances is equal to the reciprocal of the effective or equivalent resistance. When 'n' resistors of equal resistances R are connected in parallel, the equivalent resistance is $\frac{R}{n}$.

i.e., $\frac{1}{R_P} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} \cdots + \frac{1}{R} = \frac{n}{R}$.

Hence, $R_p = \frac{R}{n}$

The equivalent resistance in a parallel combination is less than the lowest of the individual resistances.

4.7.3 Series Connection of Parallel Resistors

If you consider the connection of a set of parallel resistors that are connected in series, you get a series – parallel circuit. Let R_1 and R_2 be connected in parallel to give an effective resistance of R_{P1}. Similarly, let R_3 and R_4 be connected in parallel to give an effective resistance of R_{P2}. Then, both of these parallel segments are connected in series (Figure 4.8).

Using equation (4.18), you get

$$\frac{1}{R_{P1}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_{P2}} = \frac{1}{R_3} + \frac{1}{R_4}$$

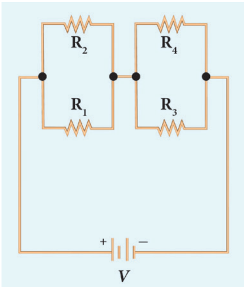


Figure 4.8 Series-parallel combination of resistors

Finally, using equation (4.12), the net effective resistance is given by $R_{total} = R_{P1} + R_{P2}$

4.7.4 Parallel Connection of Series Resistors

If you consider a connection of a set of series resistors connected in a parallel circuit, you get a parallel-series circuit. Let R_1 and R_2 be connected in series to give an effective resistance of R_{S1}. Similarly, let R_3 and R_4 be connected in series to give an effective resistance of R_{S2}. Then, both of these serial segments are connected in parallel (Figure 4.9).

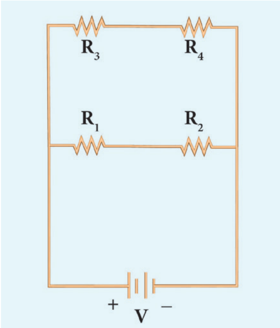


Figure 4.9 Parallel-series combination of resistors

Table 4.3 Difference between series and parallel circuit

S. No.	CRITERIA	SERIES	PARALLEL
1	Equivalent resistance	More than the highest resistance.	Less than the lowest resistance.
2	Amount of current	Current is less as effective resistance is more.	Current is more as effective resistance is less.
3	Switching ON/OFF	If one appliance is disconnected, others also do not work.	If one appliance is disconnected, others will work independently.

Using equation (4.12), you get

$R_{S1} = R_1 + R_2$, $R_{S2} = R_3 + R_4$

Finally, using equation (4.18), the net effective resistance is given by

$$\frac{1}{R_{total}} = \frac{1}{R_{S1}} + \frac{1}{R_{S2}}$$

4.7.5 Comparison between series and parallel connections

The difference between series and parallel circuits may be summed as follows in Table 4.3

4.8 HEATING EFFECT OF CURRENT

Have you ever touched the motor casing of a fan, which has been used for a few hours continuously? What do you observe? The motor casing is warm. This is due to the heating effect of current. The same can be observed by touching a bulb, which was used for a long duration. Generally, a source of electrical energy can develop a potential difference across a resistor, which is connected to that source. This potential difference constitutes a current through the resistor. For continuous drawing of current, the source has to continuously spend its energy. A part of the energy from the source can be converted into useful work and the rest will be converted into heat energy. Thus, the passage of electric current through a wire, results in the production of heat. This phenomenon is called heating effect of current. This heating effect of current is used in devices like electric heater, electric iron, etc.

4.8.1 Joule's Law of Heating

Let 'I' be the current flowing through a resistor of resistance 'R', and 'V' be the potential difference across the resistor. The charge flowing through the circuit for a time interval 't' is 'Q'.

The work done in moving the charge Q across the ends of the resistor with a potential difference of V is VQ. This energy spent by the source gets dissipated in the resistor as heat. Thus, the heat produced in the resistor is:

$$H = W = VQ$$

You know that the relation between the charge and current is Q = I t. Using this, you get

$$H = V\,I\,t \qquad (4.19)$$

From Ohm's Law, V = I R. Hence, you have

$$\mathbf{H = I^2 R\,t} \qquad (4.20)$$

This is known as Joule's law of heating.

Joule's law of heating states that the heat produced in any resistor is:

- directly proportional to the square of the current passing through the resistor.
- directly proportional to the resistance of the resistor.
- directly proportional to the time for which the current is passing through the resistor.

4.8.2 Applications of Heating Effect

1. Electric Heating Device:

The heating effect of electric current is used in many home appliances such as electric iron, electric toaster, electric oven, electric heater, geyser, etc. In these appliances Nichrome, which is an alloy of Nickel and Chromium is used as the heating element. Why? Because:

(i) it has high resistivity, (ii) it has a high melting point, (iii) it is not easily oxidized.

2. Fuse Wire:

The fuse wire is connected in series, in an electric circuit. When a large current passes through the circuit, the fuse wire melts due to Joule's heating effect and hence the circuit gets disconnected. Therefore, the circuit and the electric appliances are saved from any damage. The fuse wire is made up of a material whose melting point is relatively low.

3. Filament in bulbs:

In electric bulbs, a small wire is used, known as filament. The filament is made up of a material whose melting point is very high. When current passes through this wire, heat is produced in the filament. When the filament is heated, it glows and gives out light. Tungsten is the commonly used material to make the filament in bulbs.

Solved Problem-6

An electric heater of resistance 5 Ω is connected to an electric source. If a current of 6 A flows through the heater, then find the amount of heat produced in 5 minutes.

Solution:

Given resistance R = 5 Ω, Current I = 6 A, Time t = 5 minutes = 5 × 60 s = 300 s

Amount of heat produced, H = I^2Rt, H = $6^2 \times 5 \times 300$. Hence, H = 54000 J

4.9 ELECTRIC POWER

In general, power is defined as the rate of doing work or rate of spending energy. Similarly, the electric power is defined as the rate of consumption of electrical energy. It represents the rate at which the electrical energy is converted into some other form of energy.

Suppose a current 'I' flows through a conductor of resistance 'R' for a time 't', then the potential difference across the two ends of the conductor is 'V'. The work done 'W' to move the charge across the ends of the conductor is given by the equation (4.19) as follows:

$$W = V\,I\,t, \text{ Power } P = \frac{\text{Work}}{\text{Time}} = \frac{VIt}{t}$$

$$\mathbf{P = V\,I} \qquad (4.21)$$

Thus, the electric power is the product of the electric current and the potential difference due to which the current passes in a circuit.

4.9.1 Unit of Electric Power

The SI unit of electric power is watt. When a current of 1 ampere passes across the ends of a conductor, which is at a potential difference of 1 volt, then the electric power is

$$P = 1 \text{ volt} \times 1 \text{ ampere} = 1 \text{ watt}$$

Thus, one watt is the power consumed when an electric device is operated at a potential difference of one volt and it carries a current of one ampere. A larger unit of power, which is more commonly used is kilowatt.

DO YOU KNOW?

HORSE POWER:

The horse power (hp) is a unit in the foot-pound-second (fps) or English system, sometimes used to express the electric power. It is equal to 746 watt.

4.9.2 Consumption of electrical energy

Electricity is consumed both in houses and industries. Consumption of electricity is based on two factors: (i) Amount of electric power and (ii) Duration of usage. Electrical energy consumed is taken as the product of electric power and time of usage. For example, if 100 watt of electric power is consumed for two hours, then the power consumed is 100 × 2 = 200 watt hour. Consumption of electrical energy is measured and expressed in watt hour, though its SI unit is watt second. In practice, a larger unit of electrical energy is needed. This larger unit is kilowatt hour (kWh). One kilowatt hour is otherwise known as one unit of electrical energy. One kilowatt hour means that an electric power of 1000 watt has been utilized for an hour. Hence,

1 kWh = 1000 watt hour = 1000 × (60 × 60) watt second = 3.6×10^6 J

4.10 DOMESTIC ELECTRIC CIRCUITS

The electricity produced in power stations is distributed to all the domestic and industrial consumers through overhead and underground cables. The diagram, which shows the general scheme of a domestic electric circuit, is given in Figure 4.10.

In our homes, electricity is distributed through the domestic electric circuits wired by the electricians. The first stage of the domestic circuit is to bring the power supply to the main-box from a distribution panel, such as a transformer. The important components of the main-box are: (i) a fuse box and (ii) a meter. The meter is used to record the consumption of electrical energy. The fuse box contains either a fuse wire or a miniature circuit breaker (MCB). The function of the fuse wire or a MCB is to protect the house hold electrical appliances from overloading due to excess current.

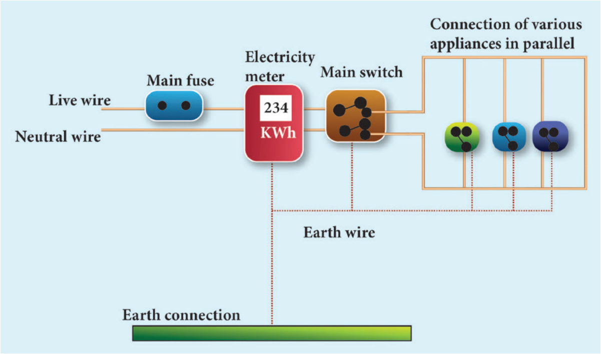


Figure 4.10 Domestic electric circuit

You have learnt about a fuse wire in section 4.8.2. An MCB is a switching device, which can be activated automatically as well as manually. It has a spring attached to the switch, which is attracted by an electromagnet when an excess current passes through the circuit. Hence, the circuit is broken and the protection of the appliance is ensured. Figure 4.11 represents a fuse and an MCB.

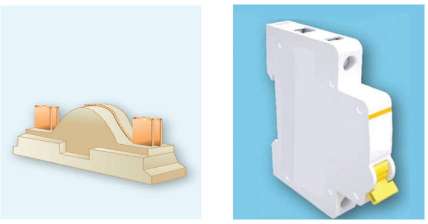


Figure 4.11 A fuse and an MCB

The electricity is brought to houses by two insulated wires. Out of these two wires, one wire has a red insulation and is called the 'live wire'. The other wire has a black insulation and is called the 'neutral wire'. The electricity supplied to your house is actually an alternating current having an electric potential of 220 V. Both, the live wire and the neutral wire enter into a box where the main fuse is connected with the live wire. After the electricity meter, these wires enter into the main switch, which is used to discontinue the electricity supply whenever required. After the main switch, these wires are connected to live wires of two separate circuits. Out of these two circuits, one circuit is of a 5 A rating, which is used to run the electric appliances with a lower power rating, such as tube lights, bulbs and fans. The other circuit is of a 15 A rating, which is used to run electric appliances with a high power rating, such as air-conditioners, refrigerators, electric iron and heaters. It should be noted that all the circuits in a house are connected in parallel, so that the disconnection of one circuit does not affect the other circuit. One more advantage of the parallel connection of circuits is that each electric appliance gets an equal voltage.

DO YOU KNOW?

In India, domestic circuits are supplied with an alternating current of potential 220/230V and frequency 50 Hz. In countries like USA and UK, domestic circuits are supplied with an alternating current of potential 110/120 V and frequency 60 Hz.

4.10.1 Overloading and Short circuiting

The fuse wire or MCB will disconnect the circuit in the event of an overloading and short circuiting. Over loading happens when a large number of appliances are connected in series to the same source of electric power. This leads to a flow of excess current in the electric circuit.

When the amount of current passing through a wire exceeds the maximum permissible limit, the wires get heated to such an extent that a fire may be caused. This is known as overloading. When a live wire comes in contact with a neutral wire, it causes a 'short circuit'. This happens when the insulation of the wires get damaged due to temperature changes or some external force. Due to a short circuit, the effective resistance in the circuit becomes very small, which leads to the flow of a large current through the wires. This results in heating of wires to such an extent that a fire may be caused in the building.

4.10.2 Earthing

In domestic circuits, a third wire called the earth wire having a green insulation is usually connected to the body of the metallic electric appliance. The other end of the earth wire is connected to a metal tube or a metal electrode, which is buried into the Earth. This wire provides a low resistance path to the electric current. The earth wire sends the current from the body of the appliance to the Earth, whenever a live wire accidentally touches the body of the metallic electric appliance. Thus, the earth wire serves as a protective conductor, which saves us from electric shocks.

4.11 LED BULB

An LED bulb is a semiconductor device that emits visible light when an electric current passes through it. The colour of the emitted light will depend on the type of materials used. With the help of the chemical compounds like Gallium Arsenide and Gallium Phosphide, the manufacturer can produce LED bulbs that radiates red, green, yellow and orange colours. Displays in digital watches and calculators, traffic signals, street lights, decorative lights, etc., are some examples for the use of LEDs.

4.11.1 Seven Segment Display

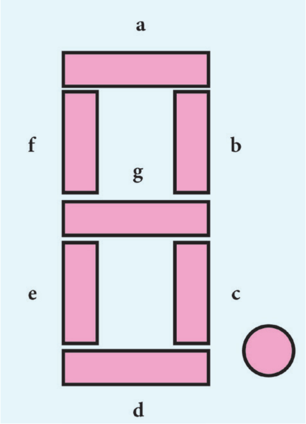


Figure 4.12 Seven segment display

A 'Seven Segment Display' is the display device used to give an output in the form of numbers or text. It is used in digital meters, digital clocks, micro wave ovens, etc. It consists of 7 segments of LEDs in the form of the digit 8. These seven LEDs are named as a, b, c, d, e, f and g (Figure 4.12). An extra 8th LED is used to display a dot.

4.11.2 Merits of a LED bulb

1. As there is no filament, there is no loss of energy in the form of heat. It is cooler than the incandescent bulb.
2. In comparison with the fluorescent light, the LED bulbs have significantly low power requirement.
3. It is not harmful to the environment.
4. A wide range of colours is possible here.
5. It is cost-efficient and energy efficient.
6. Mercury and other toxic materials are not required.

One way of overcoming the energy crisis is to use more LED bulbs.

4.12 LED TELEVISION

LED Television is one of the most important applications of Light Emitting Diodes. An LED TV is actually an LCD TV (Liquid Crystal Display) with LED display. An LED display uses LEDs for backlight and an array of LEDs act as pixels. LEDs emitting white light are used in monochrome (black and white) TV; Red, Green and Blue (RGB) LEDs are used in colour television. The first LED television screen was developed by James P. Mitchell in 1977. It was a monochromatic display. But, after about three decades, in 2009, SONY introduced the first commercial LED Television.

4.12.1 Advantages of LED television

- It has brighter picture quality.
- It is thinner in size.
- It uses less power and consumes very less energy.
- Its life span is more.
- It is more reliable.

Points to Remember

- The magnitude of current is defined as the rate of flow of charges in a conductor.
- The SI unit of electric current is ampere (A).
- The SI unit of electric potential and potential difference is volt (V).
- An electric circuit is a network of electrical components, which forms a continuous and closed path for an electric current to pass through it.
- The parameters of conductors like its length, area of cross-section and material, affect the resistance of the conductor.
- SI unit of electrical resistivity is ohm metre. The resistivity is a constant for a given material.
- The reciprocal of electrical resistivity of a material is called its electrical conductivity.

  $$\sigma = \frac{1}{\rho}$$
- The passage of electric current through a wire results in the production of heat. This phenomenon is called heating effect of current.
- One horse power is equal to 746 watts.
- The function of a fuse wire or a MCB is to protect the house hold electrical appliances from excess current due to overloading or a short circuit.

Solved Problems

1. Two bulbs are having the ratings as 60 W, 220 V and 40 W, 220 V respectively. Which one has a greater resistance?

Solution:

Electric power P = $\frac{V^2}{R}$

For the same value of V, R is inversely proportional to P.

Therefore, lesser the power, greater the resistance

Hence, the bulb with 40 W, 220 V rating has a greater resistance.

2. Calculate the current and the resistance of a 100 W, 200 V electric bulb in an electric circuit.

Solution:

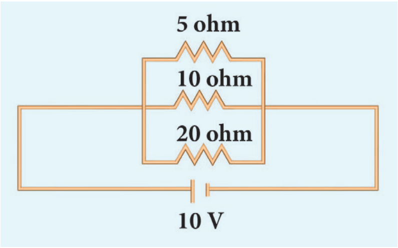
Power P = 100 W and Voltage V = 200 V

Power P = V I

So, Current, $I = \frac{P}{V} = \frac{100}{20} = 0.5$ A

Resistance, $R = \frac{V}{I} = \frac{200}{0.5} = 400\ \Omega$

3. In the circuit diagram given below, three resistors R_1, R_2 and R_3 of 5 Ω, 10 Ω and 20 Ω respectively are connected as shown. Calculate:



A) Current through each resistor
B) Total current in the circuit
C) Total resistance in the circuit

Solution:

A) Since the resistors are connected in parallel, the potential difference across each resistor is same (i.e. V=10V)

Therefore, the current through R_1 is,

$$I_1 = \frac{V}{R_1} = \frac{10}{5} = 2\ A$$

Current through $R_2 = I_2 = \frac{V}{R_2} = \frac{10}{10} = 1\ A$

Current through $R_3 = I_3 = \frac{V}{R_3} = \frac{10}{20} = 0.5\ A$

B) Total current in the circuit, $I = I_1 + I_2 + I_3$

$$= 2 + 1 + 0.5 = 3.5\ A$$

C) Total resistance in the circuit $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$$= \frac{1}{5} + \frac{1}{10} + \frac{1}{20}$$

$$= \frac{4+2+1}{20}$$

$$\frac{1}{R_P} = \frac{7}{20}$$

Hence, $R_P = \frac{20}{7} = 2.857\ \Omega$

4. Three resistors of 1 Ω, 2 Ω and 4 Ω are connected in parallel in a circuit. If a 1 Ω resistor draws a current of 1 A, find the current through the other two resistors.

Solution:

$R_1 = 1\ \Omega$, $R_2 = 2\ \Omega$, $R_3 = 4\ \Omega$ Current $I_1 = 1\ A$

The potential difference across the 1 Ω resistor $= I_1 R_1 = 1 \times 1 = 1\ V$

Since, the resistors are connected in parallel in the circuit, the same potential difference will exist across the other resistors also.

So, the current in the 2 Ω resistor, $\frac{V}{R_2} = \frac{1}{2} = 0.5\ A$

Similarly, the current in the 4 Ω resistor,

$$\frac{V}{R_3} = \frac{1}{4} = 0.25\ A$$

TEXTBOOK EVALUATION

9STERC

I. Choose the best answer

1. Which of the following is correct?
   a) Rate of change of charge is electrical power.
   b) Rate of change of charge is current.
   c) Rate of change of energy is current.
   d) Rate of change of current is charge.

2. SI unit of resistance is
   a) mho b) joule
   c) ohm d) ohm meter

3. In a simple circuit, why does the bulb glow when you close the switch?
   a) The switch produces electricity.
   b) Closing the switch completes the circuit.
   c) Closing the switch breaks the circuit.
   d) The bulb is getting charged.

4. Kilowatt hour is the unit of
   a) resistivity b) conductivity
   c) electrical energy d) electrical power

II. Fill in the blanks

1. When a circuit is open, ______________ cannot pass through it.
2. The ratio of the potential difference to the current is known as _________.
3. The wiring in a house consists of __________ circuits.
4. The power of an electric device is a product of _________ and ___________.
5. LED stands for ______________________.

III. State whether the following statements are true or false: If false correct the statement.

1. Ohm's law states the relationship between power and voltage.
2. MCB is used to protect house hold electrical appliances.
3. The SI unit for electric current is the coulomb.
4. One unit of electrical energy consumed is equal to 1000 kilowatt hour.
5. The effective resistance of three resistors connected in series is lesser than the lowest of the individual resistances.

IV. Match the items in column-I to the items in column-II:

Column - I	Column - II
(i) electric current	(a) volt
(ii) potential difference	(b) ohm meter
(iii) specific resistance	(c) watt
(iv) electrical power	(d) joule
(v) electrical energy	(e) ampere

V. Assertion and reason type questions:

Mark the correct choice as

a) if both the assertion and the reason are true and the reason is the correct explanation of the assertion.

b) if both the assertion and the reason are true, but the reason is not the correct explanation of the assertion.

c) if the assertion is true, but the reason is false.

d) if the assertion is false, but the reason is true.

1. **Assertion:** Electric appliances with a metallic body have three wire connections.

   Reason: Three pin connections reduce heating of the connecting wires

2. **Assertion:** In a simple battery circuit the point of highest potential is the positive terminal of the battery.

   Reason: The current flows towards the point of the highest potential

3. **Assertion:** LED bulbs are far better than incandescent bulbs.

   Reason: LED bulbs consume less power than incandescent bulbs.

VI. Very short answer questions.

1. Define the unit of current.
2. What happens to the resistance, as the conductor is made thicker?
3. Why is tungsten metal used in bulbs, but not in fuse wires?
4. Name any two devices, which are working on the heating effect of the electric current.

VII. Short answer questions

1. Define electric potential and potential difference.
2. What is the role of the earth wire in domestic circuits?
3. State Ohm's law.
4. Distinguish between the resistivity and conductivity of a conductor.

5. What connection is used in domestic appliances and why?

VIII. Long answer questions.

1. With the help of a circuit diagram derive the formula for the resultant resistance of three resistances connected: a) in series and b) in parallel

2. a) What is meant by electric current?
   b) Name and define its unit.
   c) Which instrument is used to measure the electric current? How should it be connected in a circuit?

3. a) State Joule's law of heating.
   b) An alloy of nickel and chromium is used as the heating element. Why?
   c) How does a fuse wire protect electrical appliances?

4. Explain about domestic electric circuits. (circuit diagram not required)

5. a) What are the advantages of LED TV over the normal TV?
   b) List the merits of LED bulb.

IX. Numerical problems:

1. An electric iron consumes energy at the rate of 420 W when heating is at the maximum rate and 180 W when heating is at the minimum rate. The applied voltage is 220 V. What is the current in each case?

2. A 100 watt electric bulb is used for 5 hours daily and four 60 watt bulbs are used for 5 hours daily. Calculate the energy consumed (in kWh) in the month of January.

3. A torch bulb is rated at 3 V and 600 mA. Calculate it's
   a) power
   b) resistance
   c) energy consumed if it is used for 4 hour.

4 A piece of wire having a resistance R is cut into five equal parts.
   a) How will the resistance of each part of the wire change compared with the original resistance?
   b) If the five parts of the wire are placed in parallel, how will the resistance of the combination change?
   c) What will be ratio of the effective resistance in series connection to that of the parallel connection?

XI. HOTS:

1. Two resistors when connected in parallel give the resultant resistance of 2 ohm; but when connected in series the effective resistance becomes 9 ohm. Calculate the value of each resistance.

2. How many electrons are passing per second in a circuit in which there is a current of 5 A?

3. A piece of wire of resistance 10 ohm is drawn out so that its length is increased to three times its original length. Calculate the new resistance.

REFERENCE BOOKS

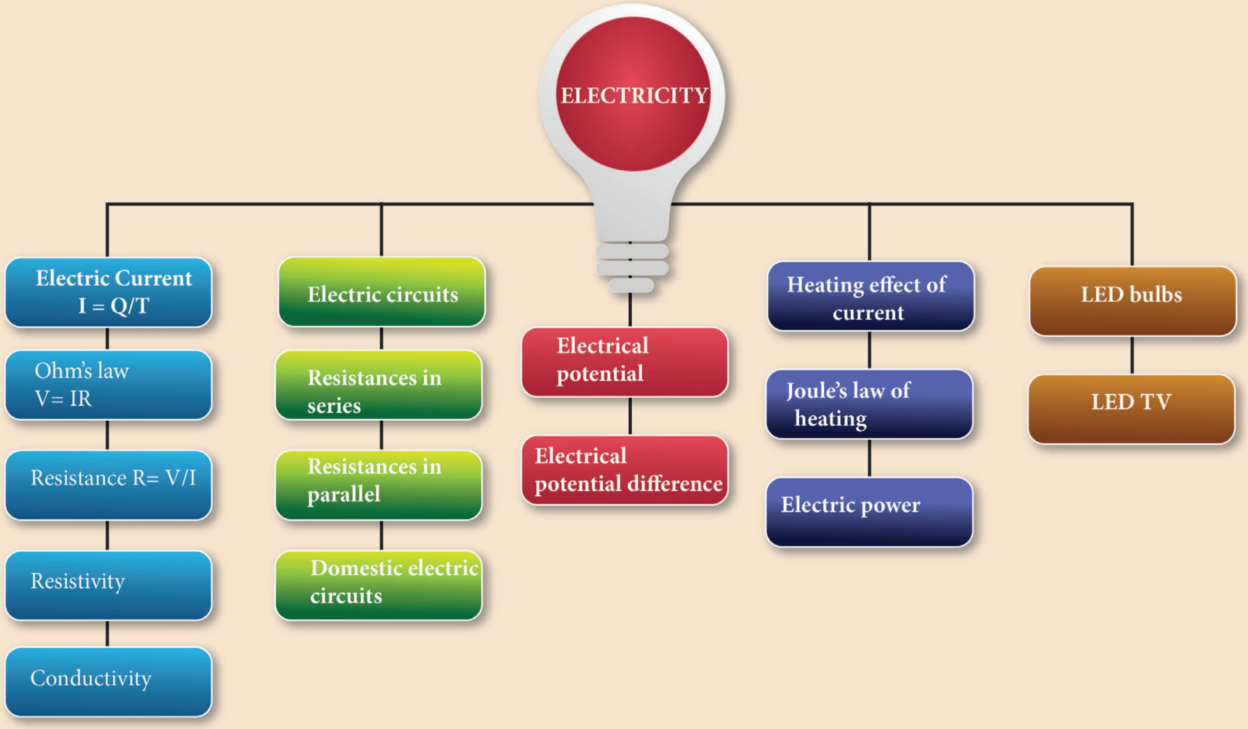
1. Electrodynamics by Griffiths
2. Fundamentals of Electric Circuits by Charles Alexander

INTERNET RESOURCES

https://www.elprocus.com/basic-electrical-circuits-and-their-working-for-electrical-engineers/

https://www.physicsclassroom.com/calcpad/circuits

CONCEPT MAP



ICT CORNER

Ohm's Law

In this activity you will be able to (i) verify Ohm's law (ii) understand the relation between current, voltage and resistance.

Steps

- Open the browser and type "olabs.edu.in" in the address bar. Click physics tab and then click "Ohm's law and resistance" under class 10 section. Go to "simulator" tab to do the experiment.
- Construct the electric circuit as per the connection diagram by clicking "show circuit diagram" tab. You can connect wires between electric component by dragging the mouse between the component.
- Switch on the key and note down the voltage (V) and curren (I). Find the value of resistance using the formula $R = \frac{V}{I}$. Repeat the experiment for different values of voltage and current. Check whether the resistance remains constant.
- Find the value of Resistance/(length (in Cm)). Enter the value of resistance and resistance per unit length in the result. Verify the answer.

Note:

1. One time sign up is needed to do simulation. Then login using that username and password.
2. Read theory, procedure and animation to get the theory by clicking the corresponding tab.

Link

URL:http://amrita.olabs.edu.in/?sub=1&brch=4&sim=99&cnt=4

B375_10_SCIENCE_EM

UNIT 5

ACOUSTICS

Learning Objectives

25NGAR

By the end of this section, the students will be able to:

- Understand how sound is produced and transmitted.
- Relate the speed of sound, its frequency, and its wavelength.
- Know the speed of sound in various media.
- Explain the factors affecting the speed of sound in a gaseous medium.
- Demonstrate the phenomenon of reflection of sound.
- Determine the speed of sound using the method of echo.
- Understand Doppler Effect.
- Solve numerical problems related to the above topics.

INTRODUCTION

Sound plays a major role in our lives. We communicate with each other mainly through sound. In our daily life, we hear a variety of sounds produced by different sources like humans, animals, vehicle horns, etc. Hence, it becomes inevitable to understand how sound is produced, how it is propagated and how you hear the sound from various sources. It is sometimes misinterpreted that acoustics only deals with musical instruments and design of auditoria and concert halls. But, acoustics is a branch of physics that deals with production, transmission, reception, control, and effects of sound. You have studied about propagation and properties of sound waves in IX standard. In this lesson we will study about reflection of sound waves, Echo and Doppler effect.

5.1 SOUND WAVES

When you think about sound, the questions that arise in your minds are: How is sound produced? How does sound reach our ears from various sources? What is sound? Is it a force or energy? Let us answer all these questions.

By touching a ringing bell or a musical instrument while it is producing music, you can conclude that sound is produced by vibrations. The vibrating bodies produce energy in the form of waves, which are nothing but sound waves (Figure 5.1).

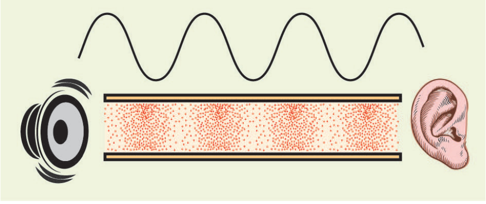


Figure 5.1 Production of sound waves

Suppose you and your friend are on the Moon. Will you be able to hear any sound produced by your friend? As the Moon does not have air, you will not be able to hear any sound produced by your friend. Hence, you understand that the sound produced due to the vibration of different bodies needs a material medium like air, water, steel, etc, for its propagation. Hence, sound can propagate through a gaseous medium or a liquid medium or a solid medium.

ACTIVITY 1

Take a squeaky toy or old mobile phone and put it inside a plastic bag. Seal the bag with the help of a candle or with a thread. Fill a bucket with water and place the bag in the water bucket and squeeze the toy or ring the mobile. You will hear a low sound. Now place your ear against the side of the bucket and squeeze the toy or ring the mobile phone again. You will hear a louder sound.

5.1.1 Longitudinal Waves

Sound waves are longitudinal waves that can travel through any medium (solids, liquids, gases) with a speed that depends on the properties of the medium. As sound travels through a medium, the particles of the medium vibrate along the direction of propagation of the wave. This displacement involves the longitudinal displacements of the individual molecules from their mean positions. This results in a series of high and low pressure regions called compressions and rarefactions as shown in figure 5.2.

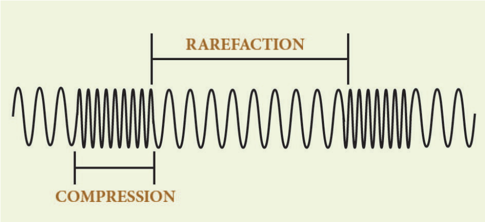


Figure 5.2 Sound propagates as longitudinal waves

5.1.2 Categories of sound waves based on their frequencies

(i) Audible waves – These are sound waves with a frequency ranging between 20 Hz and 20,000 Hz. These are generated by vibrating bodies such as vocal cords, stretched strings etc.

(ii) Infrasonic waves – These are sound waves with a frequency below 20 Hz that cannot be heard by the human ear. e.g., waves produced during earth quake, ocean waves, sound produced by whales, etc.

(iii) Ultrasonic waves – These are sound waves with a frequency greater than 20 kHz, Human ear cannot detect these waves, but certain creatures like mosquito, dogs, bats, dolphins can detect these waves. e.g., waves produced by bats.

5.1.3 Difference between the sound and light waves

S.No.	SOUND	LIGHT
1	Medium is required for the propagation.	Medium is not required for the propagation.
2	Sound waves are longitudinal.	Light waves are transverse.
3	Wavelength ranges from 1.65 cm to 1.65 m.	Wavelength ranges from 4×10^{-7} m to 7×10^{-7} m.
4	Sound waves travel in air with a speed of about 340 m s^{-1} at NTP.	Light waves travel in air with a speed of 3×10^{8} m s^{-1}.

5.1.4 Velocity of sound waves

When you talk about the velocity associated with any wave, there are two velocities, namely particle velocity and wave velocity. SI unit of velocity is metre (m)

Particle velocity:

The velocity with which the particles of the medium vibrate in order to transfer the energy in the form of a wave is called particle velocity.

Wave velocity:

The velocity with which the wave travels through the medium is called wave velocity. In other words, the distance travelled by a sound wave in unit time is called the velocity of a sound wave.

$$\therefore \text{Velocity} = \frac{\text{Distance}}{\text{Time taken}}$$

If the distance travelled by one wave is taken as one wavelength (λ) and, the time taken for this propagation is one time period (T), then, the expression for velocity can be written as

$$\therefore V = \frac{\lambda}{T} \qquad (5.1)$$

Therefore, velocity can be defined as the distance travelled per second by a sound wave. Since, Frequency (n) =1/T, equation (5.1) can be written as

$$V = n\lambda \qquad (5.2)$$

Velocity of a sound wave is maximum in solids because they are more elastic in nature than liquids and gases. Since, gases are least elastic in nature, the velocity of sound is the least in a gaseous medium.

So, $v_S > v_L > v_G$

5.1.5 Factors affecting velocity of sound

In the case of solids, the elastic properties and the density of the solids affect the velocity of sound waves. Elastic property of solids is characterized by their elastic moduli. The speed of sound is directly proportional to the square root of the elastic modulus and inversely proportional to the square root of the density. Thus the velocity of sound in solids decreases as the density increases whereas the velocity of sound increases when the elasticity of the material increases. In the case of gases, the following factors affect the velocity of sound waves.

Effect of density: The velocity of sound in a gas is inversely proportional to the square root of the density of the gas. Hence, the velocity decreases as the density of the gas increases.

$$\mathbf{v} \propto \sqrt{\frac{1}{d}}$$

Effect of temperature: The velocity of sound in a gas is directly proportional to the square root of its temperature. The velocity of sound in a gas increases with the increase in temperature. $v \propto \sqrt{T}$. Velocity at temperature T is given by the following equation:

$$v_T = (v_o + 0.61\ T)\ m\ s^{-1}$$

Here, v_o is the velocity of sound in the gas at 0° C. For air, v_o = 331 m s^{-1}. Hence, the velocity of sound changes by 0.61 m s^{-1} when the temperature changes by one degree celsius.

Effect of relative humidity: When humidity increases, the speed of sound increases. That is why you can hear sound from long distances clearly during rainy seasons.

Speed of sound waves in different media are given in table 5.1.

Table 5.1 Speed of sound in different media

S. No.	Nature of the medium	Name of the Medium	Speed of sound (in m s^{-1})
1	Solid	Copper	5010
2		Iron	5950
3		Aluminium	6420
4	Liquid	Kerosene	1324
5		Water	1493
6		Sea water	1533
7	Gas	Air (at 0° C)	331
8		Air (at 20° C)	343

Example Problem 5.1

1. At what temperature will the velocity of sound in air be double the velocity of sound in air at 0° C?

Solution:

Let T° C be the required temperature. Let v_1 and v_2 be the velocity of sound at temperatures T_1K and T_2K respectively. T_1 = 273K (0° C) and T_2 = (T° C + 273)K

$$\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{273 + T}{273}} = 2$$

Here, it is given that, $v_2 / v_1 = 2$.

$$\text{So, } \frac{273 + T}{273} = 4$$

T = (273 × 4) – 273 = 819° C

5.2 REFLECTION OF SOUND

When you speak in an empty room, you hear a soft repetition of your voice. This is nothing but the reflection of the sound waves that you produce. Let us discuss about the reflection of sound in detail through the following activity.

When sound waves travel in a given medium and strike the surface of another medium, they can be bounced back into the first medium. This phenomenon is known as reflection. In simple the reflection and refraction of sound is actually similar to the reflection of light. Thus, the bouncing of sound waves from the interface between two media is termed as the reflection of sound. The waves that strike the interface are termed as the incident wave and the waves that bounce back are termed as the reflected waves, as shown in Figure 5.3

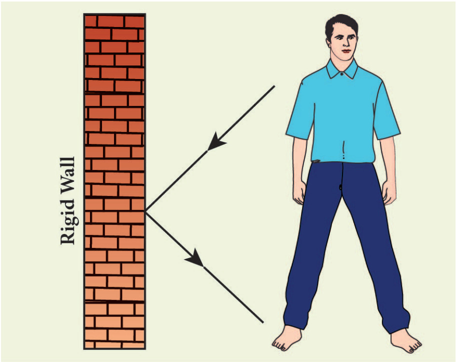


Figure 5.3 Reflection of sound

5.2.1 Laws of reflection

Like light waves, sound waves also obey some fundamental laws of reflection. The following two laws of reflection are applicable to sound waves as well.

49RYE3

❖ The incident wave, the normal to the reflecting surface and the reflected wave at the point of incidence lie in the same plane.

❖ The angle of incidence ∠i is equal to the angle of reflection ∠r.

These laws can be observed from Figure 5.4.

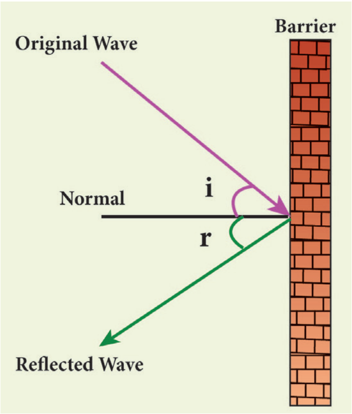


Figure 5.4 Laws of reflection

In the above Figure 5.4, the sound waves that travel towards the reflecting surface are called the incident waves. The sound waves bouncing back from the reflecting surface are called reflected waves. For all practical purposes, the point of incidence and the point of reflection is the same point on the reflecting surface.

A perpendicular line drawn at the point of incidence is called the normal. The angle which the incident sound wave makes with the normal is called the angle of incidence, 'i'. The angle which the reflected wave makes with the normal is called the angle of reflection, 'r'.

Acoustical wonder of Golconda fort (Hyderabad, Telangana)

The Clapping portico in Golconda Fort is a series of arches on one side, each smaller than the preceding one. So, a sound wave generated under the dome would get compressed and then bounce back amplified sufficiently to reach a considerable distance.

5.2.2 Reflection at the boundary of a denser medium

A longitudinal wave travels in a medium in the form of compressions and rarefactions. Suppose a compression travelling in air from left to right reaches a rigid wall. The compression exerts a force F on the rigid wall. In turn, the wall exerts an equal and opposite reaction R = – F on the air molecules. This results in a compression near the rigid wall. Thus, a compression travelling towards the rigid wall is reflected back as a compression. That is the direction of compression is reversed (Figure 5.5).

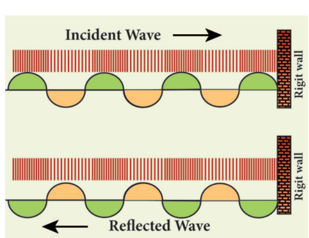
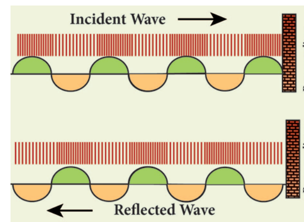


Figure 5.5 Reflection of sound at a denser medium

5.2.3 Reflection at the boundary of a rarer medium

Consider a wave travelling in a solid medium striking on the interface between the solid and the air. The compression exerts a force F on the surface of the rarer medium. As a rarer medium has smaller resistance for any deformation, the surface of separation is pushed backwards (Figure 5.6). As the particles of the rarer medium are free to move, a rarefaction is produced at the interface. Thus, a compression is reflected as a rarefaction and a rarefaction travels from right to left.



5.6 Reflection of sound at a rarer medium

More to know:

What is meant by rarer and denser medium?
The medium in which the velocity of sound increases compared to other medium is called rarer medium. (Water is rarer compared to air for sound).
The medium in which the velocity of sound decreases compared to other medium is called denser medium. (Air is denser compared to water for sound)

5.2.4 Reflection of sound in plane and curved surfaces

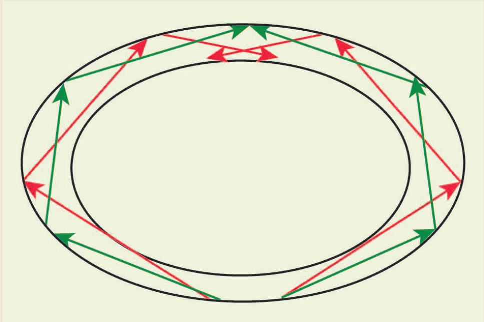
When sound waves are reflected from a plane surface, the reflected waves travel in a direction, according to the law of reflection. The intensity of the reflected wave is neither decreased nor increased. But, when the sound waves are reflected from the curved surfaces, the intensity of the reflected waves is changed. When reflected from a convex surface, the reflected waves are diverged out and the intensity is decreased. When sound is reflected from a concave surface, the reflected waves are converged and focused at a point. So the intensity of reflected waves is concentrated at a point. Parabolic surfaces are used when it is required to focus the sound at a particular point. Hence, many halls are designed with parabolic reflecting surfaces. In elliptical surfaces, sound from one focus will always be reflected to the other focus, no matter where it strikes the wall.

This principle is used in designing whispering halls. In a whispering hall, the speech of a person standing in one focus can be heard clearly by a listener standing at the other focus.

DO YOU KNOW?

Whispering Gallery

One of the famous whispering galleries is in St. Paul's cathedral church in London. It is built with elliptically shaped walls. When a person is talking at one focus, his voice can be heard distinctly at the other focus. It is due to the multiple reflections of sound waves from the curved walls.



5.3 ECHOES

An echo is the sound reproduced due to the reflection of the original sound from various rigid surfaces such as walls, ceilings, surfaces of mountains, etc.

If you shout or clap near a mountain or near a reflecting surface, like a building you can hear the same sound again. The sound, which you hear is called an echo. It is due to the reflection of sound. One does not experience any echo sound in a small room. This does not mean that sound is not reflected in a small room. This is because smaller rooms do not satisfy the basic conditions for hearing an echo.

5.3.1 Conditions necessary for hearing echo

1. The persistence of hearing for human ears is 0.1 second. This means that you can hear two sound waves clearly, if the time interval between the two sounds is at least 0.1 s. Thus, the minimum time gap between the original sound and an echo must be 0.1 s.

2. The above criterion can be satisfied only when the distance between the source of sound and the reflecting surface would satisfy the following equation:

$$\text{Velocity} = \frac{\text{distance travelled by sound}}{\text{time taken}}$$

$$v = \frac{2d}{t}$$

$$d = \frac{vt}{2}$$

Since, t = 0.1 second, then $d = \frac{v \times 0.1}{2} = \frac{v}{20}$

Thus the minimum distance required to hear an echo is 1/20th part of the magnitude of the velocity of sound in air. If you consider the velocity of sound as 344 m s^{-1}, the minimum distance required to hear an echo is 17.2 m.

5.3.2 Applications of echo

- Some animals communicate with each other over long distances and also locate objects by sending the sound signals and receiving the echo as reflected from the targets.
- The principle of echo is used in obstetric ultrasonography, which is used to create real-time visual images of the developing embryo or fetus in the mother's uterus. This is a safe testing tool, as it does not use any harmful radiations.
- Echo is used to determine the velocity of sound waves in any medium.

5.3.3 Measuring velocity of sound by echo method

Apparatus required:

A source of sound pulses, a measuring tape, a sound receiver, and a stop watch.

Procedure:

1. Measure the distance 'd' between the source of sound pulse and the reflecting surface using the measuring tape.
2. The receiver is also placed adjacent to the source. A sound pulse is emitted by the source.
3. The stopwatch is used to note the time interval between the instant at which the sound pulse is sent and the instant at which the echo is received by the receiver. Note the time interval as 't'.
4. Repeat the experiment for three or four times. The average time taken for the given number of pulses is calculated.

Calculation of speed of sound:

The sound pulse emitted by the source travels a total distance of 2d while travelling from the source to the wall and then back to the receiver. The time taken for this has been observed to be 't'. Hence, the speed of sound wave is given by:

$$\text{Speed of sound} = \frac{\text{distance travelled}}{\text{time taken}} = \frac{2d}{t}$$

5.4 APPLICATIONS REFLECTION OF SOUND

5.4.1 Sound board

These are basically curved surfaces (concave), which are used in auditoria and halls to improve the quality of sound. This board is placed such that the speaker is at the focus of the concave surface. The sound of the speaker is reflected towards the audience thus improving the quality of sound heard by the audience.

5.4.2 Ear trumpet

Ear trumpet is a hearing aid, which is useful by people who have difficulty in hearing. In this device, one end is wide and the other end is narrow. The sound from the sources fall into the wide end and are reflected by its walls into the narrow part of the device. This helps in concentrating the sound and the sound enters the ear drum with more intensity. This enables a person to hear the sound better.

5.4.3 Mega phone

A megaphone is a horn-shaped device used to address a small gathering of people. Its one end is wide and the other end is narrow. When a person speaks at the narrow end, the sound of his speech is concentrated by the multiple reflections from the walls of the tube. Thus, his voice can be heard loudly over a long distance.

5.5 DOPPLER EFFECT

The whistle of a fast moving train appears to increase in pitch as it approaches a stationary listener and it appears to decrease as the train moves away from the listener. This apparent change in frequency was first observed and explained by Christian Doppler (1803-1853), an Austrian Mathematician and Physicist. He observed that the frequency of the sound as received by a listener is different from the original frequency produced by the source whenever there is a relative motion between the source and the listener. This is known as Doppler effect This relative motion could be due to various possibilities as follows:

(i) The listener moves towards or away from a stationary source

(ii) The source moves towards or away from a stationary listener

(iii) Both source and listener move towards or away from one other

(iv) The medium moves when both source and listener are at rest

DEFINITION

When ever there is a relative motion between a source and a listener, the frequency of the sound heard by the listener is different from the original frequency of sound emitted by the source. This is known as "Doppler effect".

For simplicity of calculation, it is assumed that the medium is at rest. That is the velocity of the medium is zero.

Let S and L be the source and the listener moving with velocities v_S and v_L respectively. Consider the case of source and listener moving towards each other (Figure 5.7). As the distance between them decreases, the apparent frequency will be more than the actual source frequency.

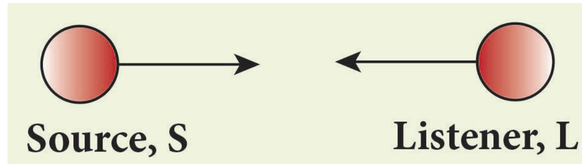


Figure 5.7 Source and listener moving towards each other

Let n and n' be the frequency of the sound produced by the source and the sound observed by the listener respectively. Then, the expression for the apparent frequency n' is

$$n' = \left(\frac{v + v_L}{v - v_s}\right)n$$

Here, v is the velocity of sound waves in the given medium. Let us consider different possibilities of motions of the source and the listener. In all such cases, the expression for the apparent frequency is given in table 5.2.

Table 5.2 Expression for apparent frequency due to Doppler effect

Case No.	Position of source and listener	Note	Expression for apparent frequency
1	❖ Both source and listener move ❖ They move towards each other	a) Distance between source and listener decreases. b) Apparent frequency is more than actual frequency.	$n' = \left(\frac{v + v_L}{v - v_s}\right)n$
2	❖ Both source and listener move ❖ They move away from each other	a) Distance between source and listener increases. b) Apparent frequency is less than actual frequency. c) v_S and v_L become opposite to that in case-1.	$n' = \left(\frac{v - v_L}{v + v_s}\right)n$
3	❖ Both source and listener move ❖ They move one behind the other ❖ Source follows the listener	a) Apparent frequency depends on the velocities of the source and the listener. b) v_S becomes opposite to that in case-2.	$n' = \left(\frac{v - v_L}{v - v_s}\right)n$

4	❖ Both source and listener move ❖ They move one behind the other ❖ Listener follows the source	a) Apparent frequency depends on the velocities of the source and the listener. b) v_S and v_L become opposite to that in case-3.	$n' = \left(\frac{v + v_L}{v + v_s}\right) n$
5	❖ Source at rest ❖ Listener moves towards the source	a) Distance between source and listener decreases. b) Apparent frequency is more than actual frequency. c) $v_S = 0$ in case-1.	$n' = \left(\frac{v + v_L}{v}\right) n$
6	❖ Source at rest ❖ Listener moves away from the source	a) Distance between source and listener increases. b) Apparent frequency is less than actual frequency. c) $v_S = 0$ in case-2.	$n' = \left(\frac{v - v_L}{v}\right) n$
7	❖ Listener at rest ❖ Source moves towards the listener	a) Distance between source and listener decreases. b) Apparent frequency is more than actual frequency. c) $v_L = 0$ in case-1.	$n' = \left(\frac{v}{v - v_s}\right) n$
8	❖ Listener at rest ❖ Source moves away from the listener	a) Distance between source and listener increases. b) Apparent frequency is less than actual frequency. c) $v_L = 0$ in case-2.	$n' = \left(\frac{v}{v + v_s}\right) n$

Suppose the medium (say wind) is moving with a velocity W in the direction of the propagation of sound. For this case, the velocity of sound, 'v' should be replaced with (v + W). If the medium moves in a direction opposite to the propagation of sound, then 'v' should be replaced with (v – W).

Solved problems

1. A source producing a sound of frequency 90 Hz is approaching a stationary listener with a speed equal to (1/10) of the speed of sound. What will be the frequency heard by the listener?

Solution: When the source is moving towards the stationary listener, the expression for apparent frequency is

$$n' = \left(\frac{v}{v - v_s}\right) n$$

$$= \left(\frac{v}{v - \left(\frac{1}{10}\right) v}\right) n = \left(\frac{10}{9}\right) n$$

$$= \left(\frac{10}{9}\right) \times 90 = 100 \text{ Hz}$$

2. A source producing a sound of frequency 500 Hz is moving towards a listener with a velocity of 30 m s^{-1}. The speed of the sound is 330 m s^{-1}. What will be the frequency heard by listener?

Solution: When the source is moving towards the stationary listener, the expression for apparent frequency is

$$n' = \left(\frac{v}{v - v_s}\right)n$$

$$n' = \left(\frac{330}{330 - 30}\right)\times 500$$

= 550 Hz

3. A source of sound is moving with a velocity of 50 m s^{-1} towards a stationary listener. The listener measures the frequency of the source as 1000 Hz. what will be the apparent frequency of the source when it is moving away from the listener after crossing him? (velocity of sound in the medium is 330 m s^{-1})

Solution: When the source is moving towards the stationary listener, the expression for apparent frequency is

$$n' = \left(\frac{v}{v - v_s}\right)n$$

$$1000 = \left(\frac{330}{330 - 50}\right) n$$

$$n = \left(\frac{1000 \times 280}{330}\right)$$

n = 848.48 Hz.

The actual frequency of the sound is 848.48 Hz. When the source is moving away from the stationary listener, the expression for apparent frequency is

$$n' = \left(\frac{v}{v + v_s}\right)n$$

$$= \left(\frac{330}{330 + 50}\right)\times 848.48$$

= 736.84 Hz

4. A source and listener are both moving towards each other with a speed v/10 where v is the speed of sound. If the frequency of the note emitted by the source is f, what will be the frequency heard by the listener?

Solution: When source and listener are both moving towards each other, the apparent frequency is

$$n' = \left(\frac{v + v_l}{v - v_s}\right).n$$

$$n' = \left(\frac{v + \frac{v}{10}}{v - \frac{v}{10}}\right).n$$

$$n' = \frac{11}{9}.f$$

= 1.22 f

5. At what speed should a source of sound move away from a stationary observer so that observer finds the apparent frequency equal to half of the original frequency?

Solution: When the source is moving away from the stationary listener, the expression for the apparent frequency is

$$n' = \left(\frac{v}{v + v_s}\right).n$$

$$\frac{n}{2} = \left(\frac{v}{v + v_s}\right).n$$

$$V_s = V$$

5.5.1 Conditions for no Doppler effect

Under the following circumstances, there will be no Doppler effect and the apparent frequency as heard by the listener will be the same as the source frequency.

(i) When source (S) and listener (L) both are at rest.

(ii) When S and L move in such a way that distance between them remains constant.

(iii) When source S and L are moving in mutually perpendicular directions.

(iv) If the source is situated at the center of the circle along which the listener is moving.

5.5.2 Applications of Doppler effect

(a) To measure the speed of an automobile

An electromagnetic wave is emitted by a source attached to a police car. The wave is reflected by a moving vehicle, which acts as a moving source. There is a shift in the frequency of the reflected wave. From the frequency shift, the speed of the car can be determined. This helps to track the over speeding vehicles.

(b) Tracking a satellite

The frequency of radio waves emitted by a satellite decreases as the satellite passes away from the Earth. By measuring the change in the frequency of the radio waves, the location of the satellites is studied.

(c) RADAR (RAdio Detection And Ranging)

In RADAR, radio waves are sent, and the reflected waves are detected by the receiver of the RADAR station. From the frequency change, the speed and location of the aeroplanes and aircrafts are tracked.

(d) SONAR

In SONAR, by measuring the change in the frequency between the sent signal and received signal, the speed of marine animals and submarines can be determined.

Points to Remember

- Wave velocity is the velocity with which the wave travels through the medium.
- Velocity of a sound wave is maximum in solids because they are more elastic in nature than liquids and gases. Since gases are least elastic in nature.
- Infrasonic waves are sound wave with a frequency below 20 Hz. A human ear cannot hear these waves.
- Ultrasonic waves are sound waves with frequency greater than 20 kHz, A human ear cannot detect these waves.
- Reflection of sound waves obey the laws of reflection.
- when a compression hits the boundary of a rarer medium, it is reflected as a rarefaction.
- An echo is the sound reproduced due to the reflection of the original sound wave.
- The minimum distance between the source and the reflecting surface should be 17.2 m to hear an echo clearly.
- "The apparent frequency" is the frequency of the sound as heard by the listener.

10th_Science_Unit-5.indd 69 21-02-2019 18:36:51

TEXTBOOK EVALUATION

83YVMP

I. Choose the correct answer

1. When a sound wave travels through air, the air particles

   a) vibrate along the direction of the wave motion
   b) vibrate but not in any fixed direction
   c) vibrate perpendicular to the direction of the wave motion
   d) do not vibrate

2. Velocity of sound in a gaseous medium is 330 m s^{-1}. If the pressure is increased by 4 times without causing a change in the temperature, the velocity of sound in the gas is

   a) 330 m s^{-1} b) 660 m s^{1}
   c) 156 m s^{-1} d) 990 m s^{-1}

3. The frequency, which is audible to the human ear is

   a) 50 kHz b) 20 kHz
   c) 15000 kHz d) 10000 kHz

4. The velocity of sound in air at a particular temperature is 330 m s^{-1}. What will be its value when temperature is doubled and the pressure is halved?

   a) 330 m s^{-1} b) 165 m s^{-1}
   c) $330 \times \sqrt{2}$ m s^{-1} d) $320 / \sqrt{2}$ m s^{-1}

5. If a sound wave travels with a frequency of 1.25×10^{4} Hz at 344 m s^{-1}, the wavelength will be

   a) 27.52 m b) 275.2 m
   c) 0.02752 m d) 2.752 m

6. The sound waves are reflected from an obstacle into the same medium from which they were incident. Which of the following changes?

   a) speed b) frequency
   c) wavelength d) none of these

7. Velocity of sound in the atmosphere of a planet is 500 m s^{-1}. The minimum distance between the sources of sound and the obstacle to hear the echo, should be

   a) 17 m b) 20 m c) 25 m d) 50 m

II. Fill up the blanks

1. Rapid back and forth motion of a particle about its mean position is called ______
2. If the energy in a longitudinal wave travels from south to north, the particles of the medium would be vibrating in ______
3. A whistle giving out a sound of frequency 450 Hz, approaches a stationary observer at a speed of 33 m s^{-1}. The frequency heard by the observer is (speed of sound = 330 m s^{-1}) ______.
4. A source of sound is travelling with a velocity 40 km/h towards an observer and emits a sound of frequency 2000 Hz. If the velocity of sound is 1220 km/h, then the apparent frequency heard by the observer is ____________.

III. True or false:- (If false give the reason)

1. Sound can travel through solids, gases, liquids and even vacuum.
2. Waves created by Earth Quake are Infrasonic.
3. The velocity of sound is independent of temperature.
4. The Velocity of sound is high in gases than liquids.

IV. Match the following

1. Infrasonic	-	(a) Compressions
2. Echo	-	(b) 22 kHz
3. Ultrasonic	-	(c) 10 Hz
4. High pressure region	-	(d) Ultrasonography

V. Assertion and Reason Questions

Mark the correct choice as

a. If both the assertion and the reason are true and the reason is the correct explanation of the assertion.

b. If both the assertion and the reason are true but the reason is not the correct explanation of the assertion.

c. Assertion is true, but the reason is false.

d. Assertion is false, but the reason is true.

1) Assertion: The change in air pressure affects the speed of sound.

Reason: The speed of sound in a gas is proportional to the square of the pressure

2) Assertion: Sound travels faster in solids than in gases.

Reason: Solid posses a greater density than that of gases.

VI. Answer very briefly

1. What is a longitudinal wave?
2. What is the audible range of frequency?
3. What is the minimum distance needed for an echo?
4. What will be the frequency sound having 0.20 m as its wavelength, when it travels with a speed of 331 m s^{-1}?
5. Name three animals, which can hear ultrasonic vibrations.

VII. Answer briefly

1. Why does sound travel faster on a rainy day than on a dry day?
2. Why does an empty vessel produce more sound than a filled one?
3. Air temperature in the Rajasthan desert can reach 46°C. What is the velocity of sound in air at that temperature? (V_0 = 331 m s^{-1})
4. Explain why, the ceilings of concert halls are curved.
5. Mention two cases in which there is no Doppler effect in sound?

VIII. Problem Corner

1. A sound wave has a frequency of 200 Hz and a speed of 400 m s^{-1} in a medium. Find the wavelength of the sound wave.
2. The thunder of cloud is heard 9.8 seconds later than the flash of lightning. If the speed of sound in air is 330 m s^{-1}, what will be the height of the cloud?
3. A person who is sitting at a distance of 400 m from a source of sound is listening to a sound of 600 Hz. Find the time period between successive compressions from the source?
4. An ultrasonic wave is sent from a ship towards the bottom of the sea. It is found that the time interval between the transmission and reception of the wave is 1.6 seconds. What is the depth of the sea, if the velocity of sound in the seawater is 1400 m s^{-1}?
5. A man is standing between two vertical walls 680 m apart. He claps his hands and hears two distinct echoes after 0.9 seconds and 1.1 second respectively. What is the speed of sound in the air?
6. Two observers are stationed in two boats 4.5 km apart. A sound signal sent by one, under water, reaches the other after 3 seconds. What is the speed of sound in the water?
7. A strong sound signal is sent from a ship towards the bottom of the sea. It is received back after 1s.What is the depth of sea given that the speed of sound in water 1450 m s^{-1}?

IX. Answer in Detail

1. What are the factors that affect the speed of sound in gases?
2. What is mean by reflection of sound? Explain:
   a) reflection at the boundary of a rarer medium
   b) reflection at the boundary of a denser medium
   c) Reflection at curved surfaces
3. a) What do you understand by the term 'ultrasonic vibration'?
   b) State three uses of ultrasonic vibrations.
   c) Name three animals which can hear ultrasonic vibrations.
4. What is an echo?
   a) State two conditions necessary for hearing an echo.
   b) What are the medical applications of echo?
   c) How can you calculate the speed of sound using echo?

X. HOT Questions

1. Suppose that a sound wave and a light wave have the same frequency, then which one has a longer wavelength?
   a) Sound   b) Light
   c) both a and b   d) data not sufficient
2. When sound is reflected from a distant object, an echo is produced. Let the distance between the reflecting surface and the source of sound remain the same. Do you hear an echo sound on a hotter day? Justify your answer.

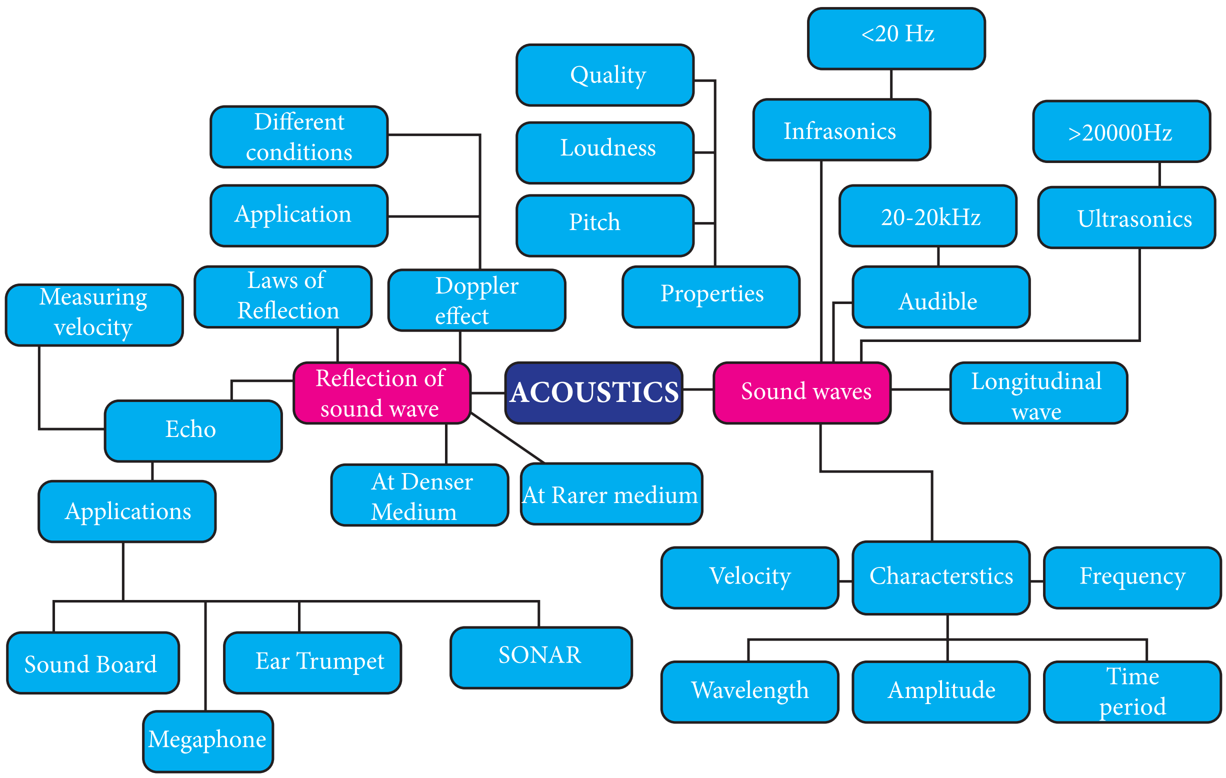
REFERENCE BOOKS

1. Fundamental Physics by K.L. Gomber and K.L. Gogia
2. Fundamentals of sound and vibration by Franky Fahy and David Thombson
3. The theory of sound by Rayleigh and John William Strutt

INTERNET RESOURCE

1. http://people.bath.ac.uk/ensmjc/Notes/acoustics.pdf

Concept Map



ICT CORNER

Doppler effect

In this activity you will be able to learn how the observed frequencies of a sound changes with the velocities of the source and the observer (Doppler effect).

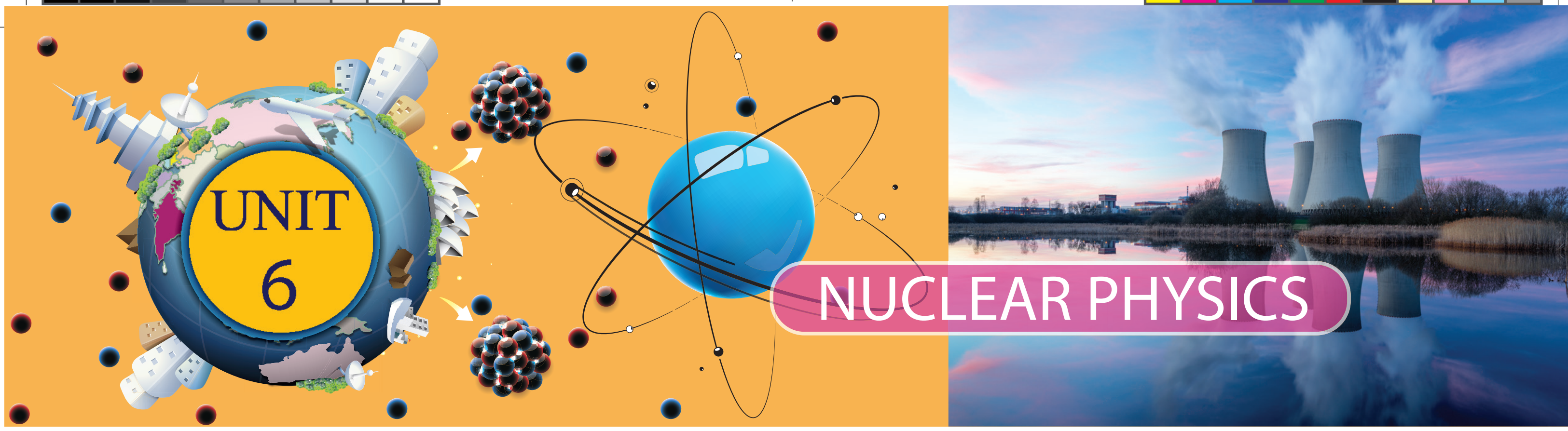
Steps

- Open the browser and type "vlab.amrita.edu" in the address bar. Click 'Physical Sciences' and then click 'Harmonic Motion and Waves Virtual Lab'. Click 'Doppler Effect' and Go to "simulator" tab to do the experiment. sign up one time with your e-mail
- Select medium of travel, detector direction and source direction by clicking the drop down menu.
- Change relative motion between source and observer by adjusting the velocity of the source and observer using the slider.
- Discuss how apparent frequency is changes with respect to actual frequency by changing position of source and listener. Also try for different source frequencies.

Link

http://vlab.amrita.edu/?sub=1&brch=201&sim=368&cnt=4

B375_10_SCIENCE_EM



UNIT 6

NUCLEAR PHYSICS

A83DR1

Learning Objectives

After learning this unit, students will be able to

- Define radio activity.
- Distingush between natural and artificial radio activity.
- Relate the properties of alpha, beta and gamma rays.
- State Soddy and Fajan's displacement law of nuclear disintegration.
- Understand the concept of nuclear fission and nuclear fusion.
- Identify fissionable materials.
- Analyze controlled and uncontrolled chain reactions.
- Explain the principle of atom bomb and hydrogen bomb.
- List the uses of radio activity.
- Understand the components of a nuclear reactor.
- Identify the precautionary measures while handling a radioactive material.

INTRODUCTION

Humans are very much interested in knowing about atoms. Things around us are made up of atoms. A Greek Philosopher 'Democritus' in 400 BC believed that matter is made up of tiny indestructible units called atoms. Later, in 1803, John Dalton considered that elements consist of atoms, which are identical in nature. J J Thomson discovered cathode rays, known as electrons, experimentally and Goldstein discovered positive rays, which were named as protons by Rutherford. In 1932, James Chadwick discovered the chargeless particles called neutrons. Presently, a large number of elementary particles like photon, meson, positron and nutrino have been discovered. In 1911, the British scientist, Ernest **Rutherford** explained that the mass of an atom is concentrated in its central part called **Nucleus**. You have already learnt about the atomic structure in the earlier classes.

6.1 RADIOACTIVITY

6.1.1 Discovery of radioactivity

In 1896, French physicist **Henri Becquerel** finished his research for the week and stored a certain amount of uranium compound away in a drawer for the week end. By chance, an unexposed photographic plate was also stored in the same drawer. After a week he returned and noticed that the film had been exposed to some radiation. He discovered that he could reproduce the effect whenever he placed uranium near a photographic film. Apparently, uranium radiated something that could affect a photographic plate. This phenomenon was called as **Radioactivity**. Uranium was identified to be a radioactive element.

Two years later, the Polish physicist **Marie Curie** and her husband **Pierre Curie** detected radioactivity in 'Pitchblende', a tiny black substance. They were not surprised at the radioactivity of pitchblende, which is known as an ore of uranium. Later, they discovered that the radiation was more intense from pure uranium. Also, it was found that the pitchblende had less concentration of uranium. They concluded that **some other substance** was present in pitchblende. After separating this new substance, they discovered that it had unknown chemical properties and it also emitted radiations spontaneously like uranium. They named this new substance as **'Radium'**.The radioactive elements emit harmful radioactive radiations like alpha rays or beta rays or gamma rays.

6.1.2 Definition of radioactivity

The nucleus of some elements is unstable. Such nuclei undergo nuclear decay and get converted into more stable nuclei. During this nuclear reaction, these nuclei emit certain harmful radiations and elementary particles. The phenomenon of nuclear decay of certain elements with the emission of radiations like alpha, beta, and gamma rays is called 'radioactivity' and the elements, which undergo this phenomenon are called 'radioactive elements'.

6.1.3 Natural Radioactivity

The elements such as uranium and radium undergo radioactivity and emit the radiations on their own without any human intervention. This phenomenon of spontaneous emission of radiation from certain elements on their own is called 'natural radioactivity'.

The elements whose atomic number is more than 83 undergo spontaneous radioactivity. Eg: uranium, radium, etc. There are only two elements, which have been identified as radioactive substances with atomic number less than 83. They are technetium (Tc) with atomic number 43 and promethium (Pm) with atomic number 61.

DO YOU KNOW? There have been 29 radioactive substances discovered so far. Most of them are rare earth metals and transition metals.

6.1.4 Artificial Radioactivity (or) Induced Radioactivity

The phenomenon by which even light elements are made radioactive, by artificial or induced methods, is called 'artificial radioactivity' or 'man-made radioactivity'.

This kind of radioactivity was discovered by Irene Curie and F.Joliot in 1934. Artificial radioactivity is induced in certain lighter elements like boron, aluminium etc., by bombarding them with radiations such as 'alpha particles' emitted during the natural radioactivity of uranium. This also results in the emission of invisible radiations and elementary particles. During such a disintegration, the nucleus which undergoes disintegration is called 'parent nucleus' and that which is produced after the disintegration is called a 'daughter nucleus'. The particle, which

Table 6.1 **Comparison between Natural and Artificial Radioactivity**

S.No.	Natural radioactivity	Artificial radioactivity
1	Emission of radiation due to self-disintegration of a nucleus.	Emission of radiation due to disintegration of a nucleus through induced process.
2	Alpha, beta and gamma radiations are emitted.	Mostly elementary particles such as neutron, positron, etc. are emitted.
3	It is a spontaneous process.	It is an induced process.
4	Exhibited by elements with atomic number more than 83.	Exhibited by elements with atomic number less than 83.
5	This cannot be controlled.	This can be controlled.

is used to induce the artificial disintegration is termed as projectile and the particle which is produced after the disintegration is termed as ejected particle. When the projectile hits the parent nucleus, it is converted into an unstable nucleus, which in turn decays spontaneously emitting the daughter nucleus along with an ejected particle.

Activity 6.1

Using the periodic table, list out the radioactive elements. Also identify the name of the groups in which they are present.

If you denote the parent and daughter nuclei as X and Y respectively, then the nuclear disintegration is represented as follows: X (P,E) Y. Here, P and E represent the projectile particle and ejected particle respectively.

Example:

$$_4Be^9 + {}_2He^4 \longrightarrow {}_6C^{13*}$$

$$_6C^{13*} \longrightarrow {}_6C^{12} + {}_0n^1$$

In the above nuclear reaction, $_6C^{13*}$ is unstable and is radioactive. This reaction can be represented as $_4Be^9$ (α, n) $_6C^{12}$

$$_4Be^9 + {}_2He^4 \longrightarrow {}_6C^{12} + {}_0n^1$$

6.1.5 Units of Radioactivity

Curie: It is the traditional unit of radioactivity. It is defined as the quantity of a radioactive substance which undergoes 3.7×10^{10} disintegrations in one second. This is actually close to the activity of 1 g of radium 226.

1 curie = 3.7×10^{10} disintegrations per second.

Rutherford (Rd): It is another unit of radioactivity. It is defined as the quantity of a radioactive substance, which produces 10^6 disintegrations in one second.

1 Rd = 10^6 disintegrations per second.

Becquerel (Bq) : It is The SI unit of radioactivity is becquerel. It is defined as the quantity of one disintegration per second.

Roentgen (R): It is The radiation exposure of γ and x-rays is measured by another unit called roentgen. One roentgen is defined as the quantity of radioactive substance which produces a charge of 2.58×10^{-4} coulomb in 1 kg of air under standard conditions of pressure, temperature and humidity.

6.2 ALPHA, BETA AND GAMMA RAYS

When a radioactive nucleus undergoes radioactivity, it emits harmful radiations. These radiations are usually comprised of any of the three types of particles. They are **alpha(α), beta (β) and gamma(γ)** rays.

DO YOU KNOW?

Uranium, named after the planet Uranus, was discovered by Martin Klaproth, a German chemist in a mineral called pitchblende.

6.2.1 Properties of Alpha, Beta and Gamma rays

These three particles possess certain similarities and dissimilarities in their properties as listed below in Table 6.2.

6.2.2 Radioactive displacement law

In 1913, Soddy and Fajan framed the displacement laws governing the daughter nucleus produced during an alpha and beta decay. They are stated below:

(i) When a radioactive element emits an alpha particle, a daughter nucleus is formed whose mass number is less by 4 units and the atomic number is less by 2 units, than the mass number and atomic number of the parent nucleus.

(ii) When a radioactive element emits a beta particle, a daughter nucleus is formed whose mass number is the same and the atomic number is more by 1 unit, than the atomic number of the parent nucleus.

Table 6.2 Properties of alpha, beta and gamma rays

Properties	α rays	β rays	γ rays
What are they?	Helium nucleus ($_2He^4$) consisting of two protons and two neutrons.	They are electrons ($_{-1}e^0$), basic elementary particle in all atoms.	They are electromagnetic waves consisting of photons.
Charge	Positively charged particles. Charge of each alpha particle = +2e	Negatively charged particles. Charge of each beta particle = –e	Neutral particles. Charge of each gamma particle = zero
Ionising power	100 time greater than β rays and 10,000 times greater than γ rays	Comparatively low	Very less ionization power
Penetrating power	Low penetrating power (even stopped by a thick paper)	Penetrating power is greater than that of α rays. They can penetrate through a thin metal foil.	They have a very high penetrating power greater than that of β rays. They can penetrate through thick metal blocks.
Effect of electric and magnetic field	Deflected by both the fields. (in accordance with Fleming's left hand rule)	Deflected by both the fields; but the direction of deflection is opposite to that for alpha rays. (in accordance with Fleming's left hand rule)	They are not deflected by both the fields.
Speed	Their speed ranges from 1/10 to 1/20 times the speed of light.	Their speed can go up to 9/10 times the speed of light.	They travel with the speed of light.

6.2.3 Alpha decay

A nuclear reaction in which an unstable parent nucleus emits an alpha particle and forms a stable daughter nucleus, is called 'alpha decay'.

E.g.: Decay of uranium (U^{238}) to thorium (Th^{234}) with the emission of an alpha particle.

$${}_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4} \quad (\alpha\text{ - decay})$$

In α - decay, the parent nucleus emits an α particle and so it is clear that for the daughter nucleus, the mass number decreases by four and the atomic number decreases by two as illustrated in Figure 6.1

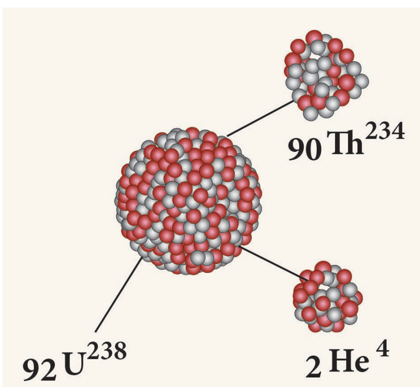


Figure 6.1 Alpha decay

6.2.4 Beta decay

A nuclear reaction, in which an unstable parent nucleus emits a beta particle and forms a stable daughter nucleus, is called 'beta decay'.

E.g.: Beta decay of phosphorous.

$${}_{15}P^{32} \longrightarrow {}_{16}S^{32} + {}_{-1}e^{0} \quad (\beta\text{ - decay})$$

In β - decay there is no change in the mass number of the daughter nucleus but the atomic number increases by one.

Note: In a nuclear reaction, the element formed as the product nucleus is identified by the atomic number of the resulting nucleus and not by its mass number.

6.2.5 Gamma decay

In a γ - decay, only the energy level of the nucleus changes. The atomic number and mass number of the radioactive nucleus remain the same.

6.3 NUCLEAR FISSION

B353TN

6.3.1 Definition

In 1939, German Scientist Otto Hahn and F.Strassman discovered that when a uranium nucleus is bombarded with a neutron, it breaks up into two smaller nuclei of comparable mass along with the emission of a few neutrons and energy. This process of breaking (splitting) up of a heavier nucleus into two smaller nuclei with the release of a large amount of energy and a few neutrons is called 'nuclear fission'.

E.g.: Nuclear fission of a uranium nucleus (U^{235})

$${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} + Q\ (\text{energy})$$

The average energy released in each fission process is about 3.2×10^{-11} J. Nuclear fission is pictorially represented in Figure 6.2.

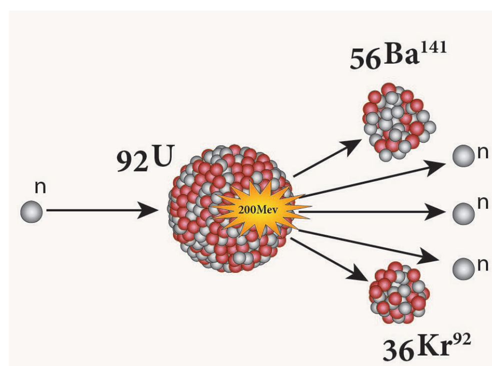


Figure 6.2 Nuclear fission

6.3.2 Fissionable materials

A fissionable material is a radioactive element, which undergoes fission in a sustained manner when it absorbs a neutron. It is also termed as 'fissile material'.

E.g.: U^{235}, plutonium (Pu^{239} and Pu^{241})

All isotopes of uranium do not undergo nuclear fission when they absorb a neutron. For example, natural uranium consists of 99.28 % of ${}_{92}U^{238}$ and 0.72 % of ${}_{92}U^{235}$. Of these two, U^{238} does not undergo fission whereas U^{235} undergoes fission. Hence, U^{235} is a fissionable material and U^{238} is non-fissionable.

There are some radioactive elements, which can be converted into fissionable material. They are called as **fertile materials**.

E.g.: Uranium-238, Thorium-232, Plutonium-240.

6.3.3 Chain Reaction

A uranium nucleus (U-235) when bombarded with a neutron undergoes fission producing three neutrons. These three neutrons in turn can cause fission in three other uranium nuclei present in the sample, thus producing nine neutrons. These nine neutrons in turn may produce twenty seven neutrons and so on. This is known as 'chain reaction'. A chain reaction is a self-propagating process in which the number of neutrons goes on multiplying rapidly almost in a geometrical progression.

Two kinds of chain reactions are possible. They are: (i) controlled chain reaction and (ii)uncontrolled chain reaction.

(a) Controlled chain reaction

In the controlled chain reaction the number of neutrons released is maintained to be one. This is achieved by absorbing the extra neutrons with a neutron absorber leaving only one neutron to produce further fission. Thus, the reaction is sustained in a controlled manner. The energy released due to a controlled chain reaction can be utilized for constructive purposes. Controlled chain reaction is used in a nuclear reactor to produce energy in a sustained and controlled manner.

(b) Uncontrolled chain reaction

In the uncontrolled chain reaction the number of neutrons multiplies indefinitely and causes fission in a large amount of the fissile material. This results in the release of a huge amount of energy within a fraction of a second. This kind of chain reaction is used in the atom bomb to produce an explosion. Figure 6.3 represents an uncontrolled chain reaction.

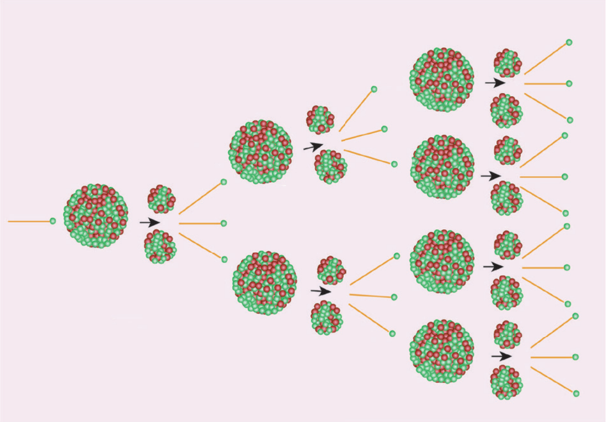


Figure 6.3 Uncontrolled chain reaction

6.3.4 Critical Mass

During a nuclear fission process, about 2 to 3 neutrons are released. But, all these neutrons may not be available to produce further fission. Some of them may escape from the system, which is termed as 'leakage of neutrons' and some may be absorbed by the non-fissionable materials present in the system. These two factors lead to the loss of neutrons. To sustain the chain reaction, the rate of production of neutrons due to nuclear fission must be more than the rate of its loss. This can be achieved only when the size (i.e., mass) of the fissionable material is equal to a certain optimum value. This is known as 'critical mass'.

The minimum mass of a fissile material necessary to sustain the chain reaction is called 'critical mass (m_c)'. It depends on the nature, density and the size of the fissile material.

If the mass of the fissile material is less than the critical mass, it is termed as 'subcritical'. If the mass of the fissile material is more than the critical mass, it is termed as 'supercritical'.

Activity 6.2

Using beads make a chain reaction model

6.3.5 Atom bomb

The atom bomb is based on the principle of uncontrolled chain reaction. In an uncontrolled chain reaction, the number of neutrons and the number of fission reactions multiply almost in a geometrical progression. This releases a huge amount of energy in a very small time interval and leads to an explosion.

Structure:

An atom bomb consists of a piece of fissile material whose mass is subcritical. This piece has a cylindrical void. It has a cylindrical fissile material which can fit into this void and its mass is also subcritical. When the bomb has to be exploded, this cylinder is injected into the void using a conventional explosive. Now, the two pieces of fissile material join to form the supercritical mass, which leads to an explosion. The structure of an atom bomb is shown in Figure 6.4

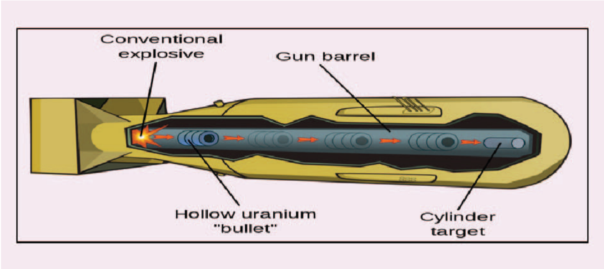


Figure 6.4 Atom bomb

During this explosion tremendous amount of energy in the form of heat, light and radiation is released. A region of very high temperature and pressure is formed in a fraction of a second along with the emission of hazardous radiation like γ rays, which adversely affect the living creatures. This type of atom bombs were exploded in 1945 at Hiroshima and Nagasaki in Japan during the World War II.

DO YOU KNOW?

Electron Volt (eV) is the unit used in nuclear physics to measure the energy of small particles. It is nothing but the energy of one electron when it is accelerated using an electric potential of one volt.

$1 eV = 1.602 \times 10^{-19}$ joule.

1 million electron volt = 1 MeV = 10^6 eV (mega electron volt)

The energy released in a nuclear fission process is about 200 MeV.

6.4 NUCLEAR FUSION

BHE2TC

You have learnt that energy can be produced when a heavy nucleus is split up into two smaller nuclei. Similarly, energy can be produced when two lighter nuclei combine to form a heavier nucleus. This phenomenon is known as nuclear fusion.

6.4.1 Definition

The process in which two lighter nuclei combine to form a heavier nucleus is termed as 'nuclear fusion'.

E.g.: ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + Q$ (Energy)

Here, ${}_1H^2$ represents an isotope of hydrogen known as 'deuterium'. The average energy released in each fusion reaction is about 3.84×10^{-12} J. Figure 6.5 represents this.

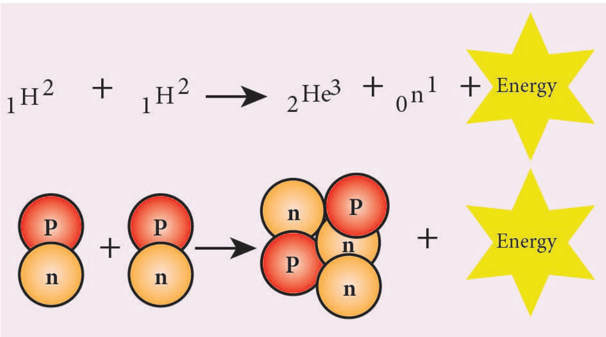


Figure 6.5 Nuclear fusion

The mass of the daughter nucleus formed during a nuclear reaction (fission and fusion) is lesser than the sum of the masses of the two parent nuclei. This difference in mass is called mass defect. This mass is converted into energy, according to the mass-energy equivalence. This concept of mass-energy equivalence was proposed by Einstein in 1905. It stated that mass can be converted into energy and vice versa. The relation between mass and energy proposed by Einstein is $\mathbf{E = mc^2}$ where c is the velocity of light in vacuum and is equal to $3 \times 10^8\ ms^{-1}$.

DO YOU KNOW?

The nuclear bomb that was dropped in Hiroshima during World War II was called as 'Little boy'. It was a gun-type bomb which used a uranium core. The bomb, which was subsequently dropped over Nagasaki was called as 'Fat man'. It was an explosion type bomb, which used a plutonium core.

6.4.2 Conditions necessary for nuclear fusion

Earth's atmosphere contains a small trace of hydrogen. If nuclear fusion is a spontaneous process at normal temperature and pressure, then a number of fusion processes would happen in the atmosphere which may lead to explosions. But, we do not encounter any such explosions. Can you explain why?

The answer is that nuclear fusion can take place only under certain conditions.

Nuclear fusion is possible only at an extremly high temperature of the order of 10^7 to 10^9 K and a high pressure to push the hydrogen nuclei closer to fuse with each other. Hence, it is named as 'Thermonuclear reaction'.

DO YOU KNOW?

Nuclear fusion is the combination of two lighter nuclei. The charge of both nuclei is positive. According to electrostatic theory, when they come closer they tend to repel each other. This repulsive force will be overcome by the kinetic energy of the nuclei at higher temperature of the order of 10^7 to 10^9 K.

6.4.3 Stellar Energy

The stars like our Sun emit a large amount of energy in the form of light and heat. This energy is termed as the stellar energy. Where does this high energy come from? All stars contain a large amount of hydrogen. The surface temperature of the stars is very high which is sufficient to induce fusion of the hydrogen nuclei.

Fusion reaction that takes place in the cores of the Sun and other stars results in an enormous amount of energy, which is called as 'stellar energy. Thus, nuclear fusion or thermonuclear reaction is the source of light and heat energy in the Sun and other stars.

6.4.4 Hydrogen Bomb

Hydrogen bomb is based on the principle of nuclear fusion. A hydrogen bomb is always designed to have an inbuilt atom bomb which creates the high temperature and pressure required for fusion when it explodes. Then, fusion takes place in the hydrogen core and leads to the release of a very large amount of energy in an uncontrolled manner. The energy released in a hydrogen bomb (or fusion bomb) is much higher than that released in an atom bomb (or fission bomb).

Table 6.3 **Features of Nuclear fission and nuclear fusion**

S.No.	NUCLEAR FISSION	NUCLEAR FUSION
1	The process of breaking up (splitting) of a heavy nucleus into two smaller nuclei is called '**nuclear fission**'.	Nuclear fusion is the combination of two lighter nuclei to form a heavier nucleus.
2	Can be performed at room temperature.	Extremely high temperature and pressure is needed.
3	Alpha, beta and gamma radiations are emitted.	Alpha rays, positrons, and neutrinos are emitted.
4	Fission leads to emission of gamma radiation. This triggers the mutation in the human gene and causes genetic transform diseases.	Only light and heat energy is emitted.

DO YOU KNOW?

Sun fuses about 620 million metric tons of hydrogen each second and radiates about 3.8×10^{26} joule of energy per second. When this energy is radiated towards the Earth, it decreases in its intensity. When it reaches the Earth its value is about 1.4 kilo joule per unit area in unit time.

6.5 USES OF RADIOACTIVITY

Many radio isotopes can be obtained from radioactivity. These radio isotopes have found wide variety of applications in the fields of medicine, agriculture, industry and archeological research.

6.5.1 Agriculture

The radio isotope of phosphorous (P-32) helps to increase the productivity of crops. The radiations from the radio isotopes can be used to kill the insects and parasites and prevent the wastage of agricultural products. Certain perishable cereals exposed to radiations remain fresh beyond their normal life, enhancing the storage time. Very small doses of radiation prevent sprouting and spoilage of onions, potatoes and gram.

6.5.2 Medicine

Medical applications of radio isotopes can be divided into two parts:

i) Diagnosis ii) Therapy

Radio isotopes are used as tracers to diagnose the nature of circulatory disorders of blood, defects of bone metabolism, to locate tumors, etc. Some of the radio isotopes which are used as tracers are: hydrogen, carbon, nitrogen, sulphur, etc.

- Radio sodium (Na^{24}) is used for the effective functioning of heart.
- Radio – Iodine (I^{131}) is used to cure goiter.
- Radio-iron is (Fe^{59}) is used to diagnose anaemia and also to provide treatment for the same.
- Radio phosphorous (P^{32}) is used in the treatment of skin diseases.

- Radio cobalt (Co^{60}) and radio-gold (Au^{198}) are used in the treatment of skin cancer.
- Radiations are used to sterilize the surgical devices as they can kill the germs and microbes.

6.5.3 Industries

In industries, radioactive isotopes are used as tracers to detect any manufacturing defects such as cracks and leaks. Packaging faults can also be identified through radio activity. Gauges, which have radioactive sources are used in many industries to check the level of gases, liquids and solids.

- An isotope of californium (Cf^{252}) is used in the airlines to detect the explosives in the luggage.
- An isotope of Americium (Am^{241}) is used in many industries as a smoke detector.

6.5.4. Archeological research

Using the technique of radio carbon dating, the age of the Earth, fossils, old paintings and monuments can be determined. In radio carbon dating, the existing amount of radio carbon is determined and this gives an estimate about the age of these things.

6.6 SAFETY MEASURES

In day to day life, you do receive some natural radiation from the Sun. The radioactive elements present in the soil and rocks, the house hold appliances like television, microwave ovens, cell phones and the X-rays used in hospitals. These radiations do not produce any severe effects as they are very low in intensity.

The second source of radiation exposure is man-made. These are due to nuclear reactors and during the testing of the nuclear devices in the atmosphere or in the ground.

Improper and careless handling of radioactive materials release harmful radiations in our environment. These radiations are very harmful to the human body. A person who is exposed to radiations very closely or for a longer duration, is at a greater health risk and can be affected genetically.

DO YOU KNOW?

How old is our mother Earth? Any guess?? It is nearly 4.54×10^9 years (around 45 Crore 40 lakh years). Wow!!

6.6.1 Permitted range

The International Commission on Radiological Protection (ICRP) has recommended certain maximum permissible exposure limits to radiation that is believed to be safe without producing any appreciable injury to a person. Safe limit of overall exposure to radiation is given as 20 milli sievert per year. In terms of roentgen, the safe limit of receiving the radiation is about 100 mR per week. If the exposure is 100 R, it may cause fatal diseases like leukemia (death of red blood corpuscle in the blood) or cancer. When the body is exposed to about 600 R, it leads to death.

DO YOU KNOW?

*Dosimeter is a device used to detect the levels of exposure to an ionizing radiation. It is frequently used in the environments where exposure to radiation may occur such as nuclear power plants and medical imaging facilities. Pocket dosimeter is used to provide the wearer with an immediate reading of his/her exposure to X-rays and γ rays.

6.6.2 Preventive measures

Figure. 6.6 Lead coated aprons model.

- Radioactive materials should be kept in a thick walled lead container.
- Lead coated aprons and lead gloves should be used while working with hazardous radioactive materials.
- You should avoid eating while handling radioactive materials.
- The radioactive materials should be handled only by tongs or by a remote control device.
- Dosimeters should be worn by the users to check the level of radiation.

6.7 NUCLEAR REACTOR

A Nuclear reactor is a device in which the nuclear fission reaction takes place in a self-sustained and controlled manner to produce electricity. The first nuclear reactor was built in 1942 at Chicago, USA.

6.7.1 Types of nuclear reactors

Breeder reactor, fast breeder reactor, pressurized water reactor, pressurized heavy water reactor, boiling water reactor, water-cooled reactor, gas-cooled reactor, fusion reactor and thermal reactor are some types of nuclear reactors, which are used in different places world-wide.

6.7.2 Components of a nuclear reactors

The essential components of a nuclear reactor are (i) fuel, (ii) moderator, (iii) control rod, (iv) coolant and (v) protection wall.

i. **Fuel:** A fissile material is used as the fuel. The commonly used fuel material is uranium.

ii. **Moderator:** A moderator is used to slow down the high energy neutrons to provide slow neutrons. Graphite and heavy water are the commonly used moderators.

iii. **Control rod:** Control rods are used to control the number of neutrons in order to have sustained chain reaction. Mostly boron or cadmium rods are used as control rods. They absorb the neutrons.

iv. **Coolant:** A coolant is used to remove the heat produced in the reactor core, to produce steam. This steam is used to run a turbine in order to produce electricity. Water, air and helium are some of the coolants.

v. **Protection wall:** A thick concrete lead wall is built around the nuclear reactor in order to prevent the harmful radiations from escaping into the environment.

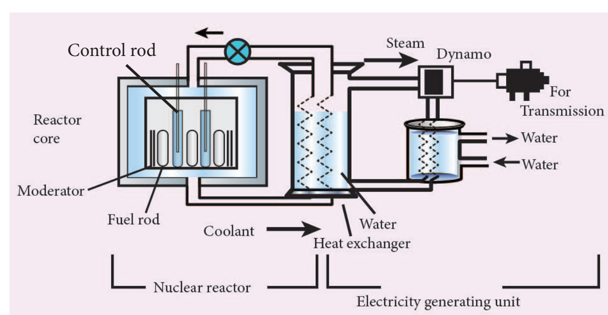


Figure 6.7 Schematic diagram of a nuclear reactor

6.7.3 Uses of a nuclear reactor

- Nuclear reactors are widely used in power generation.
- They are also used to produce radio isotopes, which are used in a variety of applications.
- Some reactors help us to do research in the field of nuclear physics.
- Breeder reactors are used to convert non-fissionable materials into fissionable materials.

6.7.4 Nuclear power plants in India

Indian Atomic Energy Commission (AEC) was established in August 1948 by the

Department of Indian Scientific Research committee at Bombay (now Mumbai) in Maharashtra. It is the nodal agency for all the research done in the field of atomic energy. Dr. Homi Jahangir Bhaba was the first chairman of Indian Atomic Energy Commission. Now, it is known as Bhaba Atomic Research Centre (BARC).

Nuclear power is the fifth largest source of power in India. Tarapur Atomic Power Station is India's first nuclear power station. Now, there are a total of seven power stations, one each in Maharashtra, Rajasthan, Gujarat, Uttar Pradesh and two in Tamilnadu. In Tamilnadu, we have nuclear power stations in Kalpakkam and Kudankulam. Apsara was the first nuclear reactor built in India and Asia. Now, there are 22 nuclear reactors which are operating in India. Some other operating reactors are

- Cirus
- Dhuruva
- Purnima

Solved problem 6.1

Identify A, B, C, and D from the following nuclear reactions.

(i) $_{13}Al^{27} + A \dashrightarrow {}_{15}P^{30} + B$

(ii) $_{12}Mg^{24} + B \dashrightarrow {}_{11}Na^{24} + C$

(iii) $_{92}U^{238} + B \dashrightarrow {}_{93}Np^{239} + D$

Solution:

(i) $_{13}Al^{27} + {}_{2}He^{4} \dashrightarrow {}_{15}P^{30} + {}_{0}n^{1}$

(ii) $_{12}Mg^{24} + {}_{0}n^{1} \dashrightarrow {}_{11}Na^{24} + {}_{1}H^{1}$

(iii) $_{92}U^{238} + {}_{0}n^{1} \dashrightarrow {}_{93}Np^{239} + {}_{-1}e^{0}$

A is alpha particle, B is neutron, C is proton, and D is electron.

Solved problem 6.2

A radon specimen emits radiation of 3.7×10^{3} GBq per second. Convert this disintegration in terms of curie. (one curie = 3.7×10^{10} disintegration per second)

$$1\ \text{Bq} = \text{one disintegration per second}$$

$$\text{one curie} = 3.7 \times 10^{10}\ \text{Bq}$$

$$1\ \text{Bq} = \frac{1}{3.7 \times 10^{10}}\ \text{curie}$$

$$\therefore\ 3.7 \times 10^{3}\ \text{G Bq} = 3.7 \times 10^{3} \times 10^{9} \times \frac{1}{3.7 \times 10^{10}}$$

$$= 100\ \text{curie}$$

Solved problem 6.3

$_{92}U^{235}$ experiences one α - decay and one β - decay. Find number of neutrons in the final daughter nucleus that is formed.

Solution:

Let X and Y be the resulting nucleus after the emission of the alpha and beta particles respectively.

$$_{92}U^{235} \xrightarrow{\alpha\ \text{decay}} {}_{90}X^{231} + {}_{2}He^{4}$$

$$_{90}X^{231} \xrightarrow{\beta\ \text{decay}} {}_{91}Y^{231} + {}_{-1}e^{0}$$

Number of neutrons = Mass number – Atomic number

= 231 – 91 = 140

Solved problem 6.4

Calculate the amount of energy released when a radioactive substance undergoes fusion and results in a mass defect of 2 kg.

Solution:

Mass defect in the reaction (m) = 2 kg

Velocity of light (c) = $3 \times 10^{8}\ m\ s^{-1}$

By Einstein's equation,

Energy released $E = mc^{2}$

So $E = 2 \times (3 \times 10^{8})^{2}$

$= 1.8 \times 10^{17}$ J

Points to Remember

- This phenomenon of spontaneous emission of radiation from certain elements on its own is called 'natural radioactivity'.
- **Curie** is defined as the quantity of a radioactive substance, which undergoes 3.7×10^{10} disintegrations in one second. This is actually close to the activity of 1 g of radium-226.

- **Rutherford (Rd)** is defined as the quantity of a radioactive substance which produces 10^6 disintegrations in one second.
  1 Rd = 10^6 disintegrations per second.

CCFRVZ

- The SI unit of radioactivity is **becquerel.** It is defined as the quantity of one disintegration per second.
- Helium nucleus ($_2He^4$) consisting of two protons and two neutrons is known as alpha particle.
- Beta particles are electrons ($_{-1}e^0$), which are the basic elementary particles present in all atoms.
- Gamma rays are electromagnetic waves consisting of photons.
- A nuclear reaction in which an unstable parent nucleus emits an alpha particle and forms a stable daughter nucleus is called as 'alpha decay'.
- A nuclear reaction in which an unstable parent nucleus emits a beta particle and forms a stable daughter nucleus is called as 'beta decay'.
- The process of breaking (splitting) up of a heavier nucleus into two smaller nuclei with the release of a large amount of energy is called **'nuclear fission'.**
- The energy released in a nuclear fission process is about 200 MeV.
- There are some radioactive elements which can be converted into a fissionable material. They are called as '**fertile materials**'. e.g. Uranium-238, Thorium-232, Plutonium-240.
- Controlled chain reaction is used in a nuclear reactor to produce energy in a sustained and controlled manner.
- The process in which two lighter nuclei combine to form a heavier nucleus is termed as **'nuclear fusion'.**
- Nuclear fusion or thermonuclear reaction is the source of light and heat energy in the Sun and other stars.
- The safe limit of receiving the radiation is about 100 mR per week.

TEXTBOOK EVALUATION

CRPQVN

I. Choose the correct answer

1. Man-made radioactivity is also known as ______________

   a. Induced radioactivity

   b. Spontaneous radioactivity

   c. Artificial radioactivity

   d. a & c

2. Unit of radioactivity is ______________

   a. roentgen　　b. curie

   c. becquerel　　d. all the above

3. Artificial radioactivity was discovered by ______________

   a. Bequerel　　b. Irene Curie

   c. Roentgen　　d. Neils Bohr

4. In which of the following, no change in mass number of the daughter nuclei takes place

   i) α decay　　ii) β decay

   iii) γ decay　　iv) neutron decay

   a. (i) is correct

   b (ii) and (iii) are correct

   c (i) & (iv) are correct

   d (ii) & (iv) are correct

5. ______________ isotope is used for the treatment of cancer.

a. Radio Iodine   b. Radio Cobalt

c. Radio Carbon   d. Radio Nickel

6. Gamma radiations are dangerous because

   a. it affects eyes & bones

   b. it affects tissues

   c. it produces genetic disorder

   d. it produces enormous amount of heat

7. ____________ aprons are used to protect us from gamma radiations

   a. Lead oxide   b. Iron

   c. Lead   d. Aluminium

8. Which of the following statements is/are correct?

   i. α particles are photons

   ii. Penetrating power of γ radiation is very low

   iii. Ionization power is maximum for α rays

   iv. Penetrating power of γ radiation is very high

   a. (i) & (ii) are correct

   b. (ii) & (iii) are correct

   c. (iv) only correct

   d. (iii) & (iv) are correct

9. Proton - Proton chain reaction is an example of

   ____

   a. Nuclear fission   b. α - decay

   c. Nuclear fusion   d. β - decay

10. In the nuclear reaction ${}_{6}X^{12} \xrightarrow{\alpha \text{ decay}} {}_{Z}Y^{A}$, the value of A & Z.

   a. 8, 6   b. 8, 4

   c. 4, 8   d. cannot be determined with the given data

11. Kamini reactor is located at ________

   a. Kalpakkam   b. Koodankulam

   c. Mumbai   d. Rajasthan

12. Which of the following is/are correct?

   i. Chain reaction takes place in a nuclear reactor and an atomic bomb.

   ii. The chain reaction in a nuclear reactor is controlled

   iii. The chain reaction in a nuclear reactor is not controlled

   iv. No chain reaction takes place in an atom bomb

   a. (i) only correct   b. (i) & (ii) are correct

   c. (iv) only correct   d. (iii) & (iv) are correct

II. Fill in the blanks

1. One roentgen is equal to ________ disintegrations per second
2. Positron is an________.
3. Anemia can be cured by ________ isotope
4. Abbreviation of ICRP_____
5. ________is used to measure exposure rate of radiation in humans.
6. _______ has the greatest penetration power.
7. ${}_{Z}Y^{A} \rightarrow {}_{Z+1}Y^{A} + X$; Then, X is ________
8. ${}_{Z}X^{A} \rightarrow {}_{Z}Y^{A}$ This reaction is possible in __________ decay.
9. The average energy released in each fusion reaction is about _______ J.
10. Nuclear fusion is possible only at an extremely high temperature of the order of ____ K.
11. The radio isotope of _______ helps to increase the productivity of crops.
12. If the radiation exposure is 100 R, it may cause __________.

III State whether the following statements are true or false: If false, correct the statement

1. Plutonium -239 is a fissionable material.
2. Elements having atomic number greater than 83 can undergo nuclear fusion.
3. Nuclear fusion is more dangerous than nuclear fission.
4. Natural uranium U-238 is the core fuel used in a nuclear reactor.
5. If a moderator is not present, then a nuclear reactor will behave as an atom bomb.
6. During one nuclear fission on an average, 2 to 3 neutrons are produced.
7. Einstein's theory of mass energy equivalence is used in nuclear fission and fusion.

IV. Match the following

Match: I

a. BARC	Kalpakkam
b. India's first atomic power station	Apsara
c. IGCAR	Mumbai
d. First nuclear reactor in India	Tarapur

Match: II

a. Fuel	lead
b. Moderator	heavy water
c. Coolant	cadmium rods
d. Shield	uranium

Match: III

a. Soddy Fajan	Natural radioactivity
b. Irene Curie	Displacement law
c. Henry Bequerel	Mass energy equivalence
d. Albert Einstein	Artificial Radioactivity

Match: IV

a. Uncontrolled fission reaction	Hydrogen Bomb
b. Fertile material	Nuclear Reactor
c. Controlled fission reaction	Breeder reactor
d. Fusion reaction	Atom bomb

Match: V

a. Co - 60	Age of fossil
b. I - 131	Function of Heart
c. Na - 24	Leukemia
d. C - 14	Thyroid disease

V. Arrange the following in the correct sequence:

1. **Arrange in descending order, on the basis of their penetration power**

   Alpha rays, beta rays, gamma rays, cosmic rays

2. **Arrange the following in the chronological order of discovery**

   Nuclear reactor, radioactivity, artificial radioactivity, discovery of radium.

VI. Use the analogy to fill in the blank

1. Spontaneous process : Natural Radioactivity, Induced process : ________
2. Nuclear Fusion : Extreme temperature, Nuclear Fission : ___________
3. Increasing crops : Radio phosphorous, Effective functioning of heart : _____
4. Deflected by electric field : α ray, Null Deflection : __________

VII. Numerical problems:

1. ${}_{88}\mathbf{Ra}^{226}$ experiences three **α** - decay. Find the number of neutrons in the daughter element.
2. A cobalt specimen emits induced radiation of 75.6 millicurie per second. Convert this disintegration in to becquerel (one curie = 3.7×10^{10} Bq)

VIII. Assertion and reason type questions:

Mark the correct choice as

(a) If both the assertion and the reason are true and the reason is the correct explanation of the assertion.

(b) If both the assertion and the reason are true, but the reason is not the correct explanation of the assertion.

(c) Assertion is true, but the reason is false.

(d) Assertion is false, but the reason is true.

1. **Assertion:** A neutron impinging on U^{235}, splits it to produce Barium and Krypton.
   Reason: U - 235 is a fissile material.
2. **Assertion**: In a β - decay, the neutron number decreases by one.
   Reason: In β - decay atomic number increases by one.
3. **Assertion**: Extreme temperature is necessary to execute nuclear fusion.
   Reason: In a nuclear fusion, the nuclei of the reactants combine releasing high energy.

4. **Assertion**: Control rods are known as 'neutron seeking rods'
   Reason: Control rods are used to perform sustained nuclear fission reaction

IX. Answer in one or two word (VSA)

1. Who discovered natural radioactivity?
2. Which radioactive material is present in the ore of pitchblende?
3. Write any two elements which are used for inducing radioactivity?
4. Write the name of the electromagnetic radiation which is emitted during a natural radioactivity.
5. If A is a radioactive element which emits an α - particle and produces $_{104}Rf^{259}$. Write the atomic number and mass number of the element A.
6. What is the average energy released from a single fission process?
7. Which hazardous radiation is the cause for the genetic disease?
8. What is the amount of radiation that may cause death of a person when exposed to it?
9. When and where was the first nuclear reactor built?
10. Give the SI unit of radioactivity.
11. Which material protects us from radiation?

X. Answer the following questions in few sentences.

1. Write any three features of natural and artificial radioactivity.
2. Define critical mass.
3. Define one roentgen.
4. State Soddy and Fajan's displacement law.
5. Give the function of control rods in a nuclear reactor.
6. In Japan, some of the new born children are having congenital diseases. Why?
7. Mr. Ramu is working as an X - ray technician in a hospital. But, he does not wear the lead aprons. What suggestion will you give to Mr. Ramu?
8. What is stellar energy?
9. Give any two uses of radio isotopes in the field of agriculture?

XI. Answer the following questions in detail.

1. Explain the process of controlled and uncontrolled chain reactions.
2. Compare the properties of alpha, beta and gamma radiations.
3. What is a nuclear reactor? Explain its essential parts with their functions.

XII. HOT Questions:

1. Mass number of a radioactive element is 232 and its atomic number is 90. When this element undergoes certain nuclear reactions, it transforms into an isotope of lead with a mass number 208 and an atomic number 82. Determine the number of alpha and beta decay that can occur.
2. 'X – rays should not be taken often'. Give the reason.
3. Cell phone towers should be placed far away from the residential area – why?

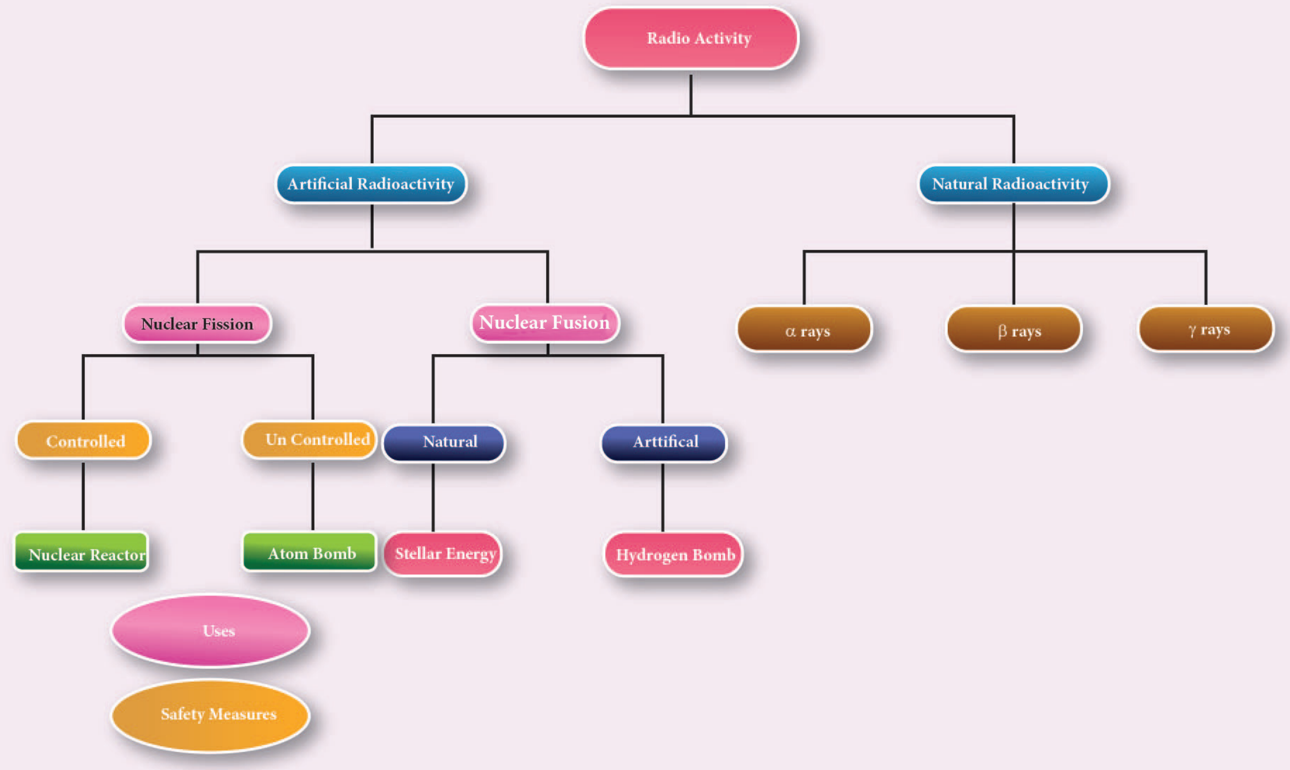
REFERENCE BOOKS

1. Physics concepts and connections – by Art Hobson Edition: Pearson education
2. Modern Physics – by Dr. R Murugesan & Er. Kiruthiga Sivaprasath – S. Chand publications

INTERNET RESOURCES

1. https://physics.columbia.edu/research/nuclear-physics
2. http://www.newworldencyclopedia.org/entry/Nuclear_physics

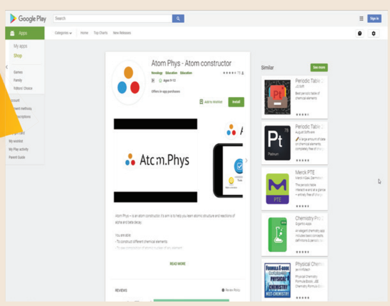
CONCEPT MAP



ICT CORNER

Modern Atomic Theory

To enable the students to build structure of different elements with electrons, protons and neutrons. They also know how new elements are formed as a result of Nuclear decays.



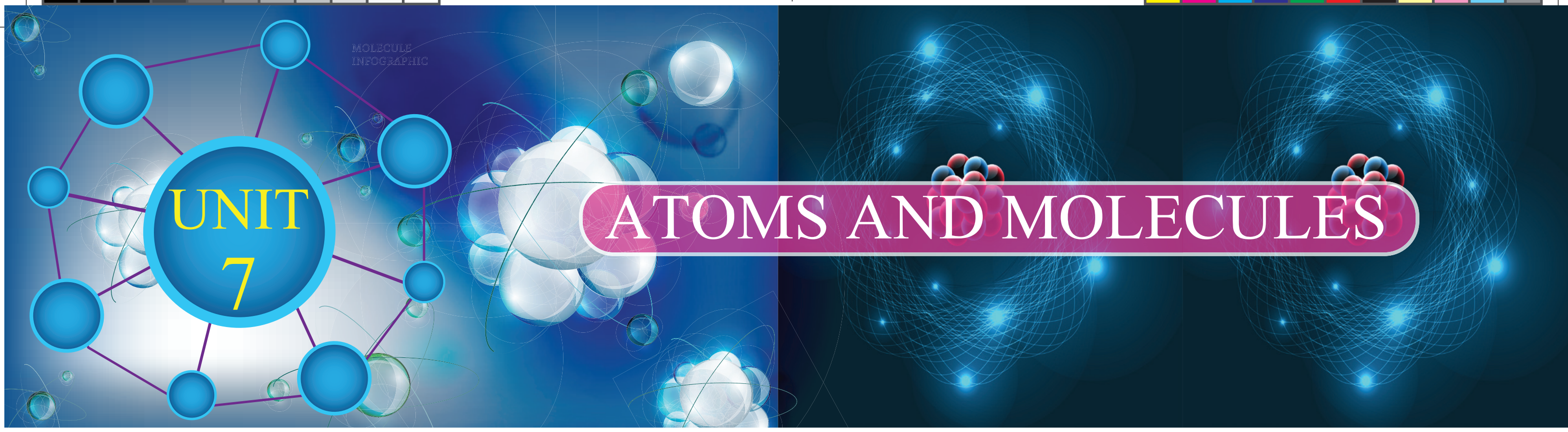
Steps

- Access and download the application 'atom.phys' in your mobile by using the provided URL or QR code.
- Click '**Modeling**' to build the structure of an element by making changes in electron, proton and neutron.
- Click '**Nuclear decays**' to know how new elements are formed because of the decay/ destruction of atoms.
- Finally click '**Tests**' to check your knowledge by answering the questions.

Cells alive

URL: https://play.google.com/store/apps/details?id=com.CowboyBebop.AtomPhys&hl=en or Scan the QR Code.

B375_10_SCIENCE_EM



UNIT 7

ATOMS AND MOLECULES

Learning Objectives

CRYLXB

At the end of the lesson the students will be able to:

- acquire the ability to learn about the atoms and molecules.
- comprehend atomic mass and molecular mass.
- have information about gram atomic mass and gram molecular mass.
- perceive the intended meaning of Avogadro's hypothesis of gases.
- interpret the application of Avogadro's hypothesis.
- determine the atomicity of a molecule.
- interpret the relation between vapour density and relative molecular mass.
- have the facts about the relationship between the volume of a gas and the number of molecules present in it.
- grasp the idea of mole concept and solve many problems using it.
- calculate the percentage of composition of a compund.

INTRODUCTION

You have learnt, in your lower classes that matter is around us everywhere. Matter is made of atoms. Curiously the idea of atom was first proposed by the Greek philosophers in the fifth century BC (BCE). But, their theory was more philosophical than scientific.

The first scientific theory of the atom was proposed by John Dalton. Few of the postulates of Dalton's theory about an atom were found incorrect by the later on studies made by J.J. Thomson, Rutherford, Neils Bohr and Schrodinger. In the light of the result of the researches most of the limitations of the Dalton's theory were removed and a new theory known as the modern atomic theory was put forward. **'The main postulates of modern atomic theory'** are as follows:

- **An atom is no longer indivisible** (after the discovery of the electron, proton, and neutron).
- Atoms of the same element may have different atomic mass. (discovery of **isotopes** $_{17}Cl^{35}$, $_{17}Cl^{37}$).
- Atoms of different elements may have same atomic masses (discovery of **Isobars** $_{18}Ar^{40}$, $_{20}Ca^{40}$).
- Atoms of one element can be transmuted into atoms of other elements. In other words, atom is no longer indestructible (discovery of **artificial transmutation**).

- Atoms may not always combine in a simple whole number ratio (E.g. Glucose $C_6H_{12}O_6$ C:H:O = 6:12:6 or 1:2:1 and Sucrose $C_{12}H_{22}O_{11}$ C:H:O = 12:22:11).
- Atom is the **smallest particle that takes part in a chemical reaction.**
- The mass of an atom can be converted into energy ($E = mc^2$).

The modern atomic theory is the basis for all the studies of chemical and physical processes that involve atoms. You have studied the most fundamental ideas about an atom in your lower classes. Let us discuss some more concepts about atoms in this lesson.

7.1 ATOM AND ATOMIC MASS

As you know, anything that has mass and occupies space is called matter. Atoms are the building blocks of matter. Since matter has mass, it must be due to its atoms. According to the modern atomic theory, an atom contains subatomic particles such as protons, neutrons and electrons. **Protons and neutrons have considerable mass, but electrons don't have such a considerable mass**. Thus, the mass of an atom is mainly contributed by its protons and neutrons and hence **the sum of the number of protons and neutrons of an atom is called its mass number**.

Individual atoms are very small and it is difficult to measure their masses. You can measure the mass of macroscopic materials in gram or kilogram. The mass of an atom is measured in atomic mass unit (amu).

Atomic mass unit is one-twelfth of the mass of a carbon-12 atom; an isotope of carbon, which contains 6 protons and 6 neutrons.

(**Note:** The symbol 'amu' is no longer used in the modern system and instead, it uses the symbol 'u' to denote unified atomic mass. The mass of a proton or neutron is approximately 1 amu).

7.1.1 Relative Atomic Mass (RAM)

As an atom is very small, its absolute mass cannot be determined directly. The early pioneers of chemistry used to measure the atomic mass of an atom relative to an atom of another element. They measured the masses of equal number of atoms of two or more elements at a time, to determine their relative masses. They established one element as a standard, gave it an arbitrary value of atomic mass and using this value they measured the relative mass of other elements. The mass obtained by this way is called relative atomic mass. In the beginning, the mass of hydrogen atom was chosen as a standard and masses of other atoms were compared with it, because of the existence of isotopic character of hydrogen (${}_1H^1$, ${}_1H^2$, ${}_1H^3$). Later hydrogen atom was replaced by oxygen atom as the standard. Now, the stable isotope of carbon (C-12) with atomic mass 12 is used as the standard for measuring the relative atomic mass of an element.

Relative atomic mass of an element is the ratio between the average mass of its isotopes to $\frac{1}{12^{th}}$ part of the mass of a carbon-12 atom. It is denoted as A_r. It is otherwise called "Standard Atomic Weight".

Relative Atomic Mass

$$(A_r) = \frac{\text{Average mass of the isotopes of the element}}{\frac{1}{12^{th}} \text{ of the mass of one Carbon-12 atom}}$$

Modern methods of determination of atomic mass by Mass Spectrometry uses C-12 as standard. For most of the elements, the relative atomic mass is very closer to a whole number and it is rounded off to a whole number, to make calculations easier. Table 7.1 lists some of the elements of periodic table and their A_r values.

Table 7.1 Relative atomic mass of elements (C-12 Scale)

Element	Symbol	A_r
Hydrogen	H	1
Carbon	C	12
Nitrogen	N	14
Oxygen	O	16
Sodium	Na	23
Magnesium	Mg	24
Sulphur	S	32

DO YOU KNOW?

Relative Atomic Mass is only a ratio, so it has no unit. If the atomic mass of an element is expressed in grams, it is called as **Gram Atomic Mass**

Gram Atomic Mass of hydrogen	= 1 g
Gram Atomic Mass of carbon	= 12 g
Gram Atomic Mass of nitrogen	= 14 g
Gram Atomic Mass of oxygen	= 16 g

7.1.2 Average Atomic Mass (AAM)

How can one measure the atomic mass of an element? It is somewhat more complicated because most of the naturally occuring elements exist as a mixture of isotopes, each of which has its own mass. Thus, it is essential to consider this isotopic mixture while calculating the atomic mass of an element.

The average atomic mass of an element is the weighted average of the masses of its naturally occurring isotopes.

But, the abundance of isotopes of each element may differ. So, the abundancy of all these isotopes are taken into consideration while calculating the atomic mass. Then, what do we mean by a weighted average? Let us consider an element which exists as a mixture of 50% of an isotope having a mass of 9 amu, and 50% of another isotope having a mass of 10 amu. Then, its average atomic mass is calculated by the following equation:

Average atomic mass

= (Mass of 1st isotope × % abundance of 1st isotope) + (Mass of 2nd isotope × % abundance of 2nd isotope)

Thus, for the given element the average

$$\text{atomic mass} = \left(9 \times \frac{50}{100}\right) + \left(10 \times \frac{50}{100}\right)$$

$$= 4.5 + 5 = 9.5 \text{ amu}$$

(Note: In the calculations involving percentages, you need to convert percentage abundance into fractional abundance. For example, 50 percent is converted into 50/100 or 0.50 as shown in the a foresaid calculation.)

The atomic masses of elements, given in the periodic table, are average atomic masses. Sometimes, the term atomic weight is used to mean average atomic mass. It is observed, from the periodic table that atomic masses of most of the elements are not whole numbers. For instance, the atomic mass of carbon given in the periodic table is 12.01 amu, not 12.00 amu. The reason is that while calculating the atomic mass of carbon, both of its natural isotopes such as carbon-12. and carbon-13 are considered. The natural abundance of C-12 and C-13 are 98.90 % and 1.10 % respectively. The average of the atomic mass of carbon is calculated as follows:

Average atomic mass of carbon

$$= \left(12 \times \frac{98.9}{100}\right) + \left(13 \times \frac{1.1}{100}\right)$$

$$= (12 \times 0.989) + (13 \times 0.011)$$

$$= 11.868 + 0.143 = 12.011 \text{ amu}$$

So it is important to understand that if it is mentioned that the atomic mass of carbon is 12 amu, it refers to the average atomic mass of the carbon isotopes, not the mass of the individual atoms of carbon.

Table 7.2 Atomic mass of some elements

Atomic Number	Name	Symbol	Atomic Mass (amu)
1	Hydrogen	H	1.008
2	Helium	He	4.003
3	Lithium	Li	6.941
4	Beryllium	Be	9.012
5	Boron	B	10.811

Calculation of average atomic mass – Solved Examples

Example 1: Oxygen is the most abundant element in both the Earth's crust and the human body. It exists as a mixture of three stable isotopes in nature as shown in Table 7.3:

Table 7.3 Isotopes of oxygen

Isotope	Mass (amu)	% abundance
${}_8O^{16}$	15.9949	99.757
${}_8O^{17}$	16.9991	0.038
${}_8O^{18}$	17.9992	0.205

The atomic mass of

$$\text{oxygen} = (15.9949 \times 0.99757) + (16.9991 \times 0.00038) + (17.9992 \times 0.00205)$$
$$= 15.999 \text{ amu.}$$

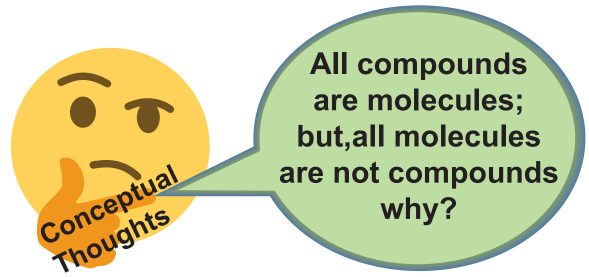
Example 2: Boron naturally occurs as a mixture of boron-10 (5 protons + 5 neutrons) and boron-11 (5 protons + 6 neutrons) isotopes. The percentage abundance of B-10 is 20 and that of B-11 is 80. Then, the atomic mass of boron is calculated as follows:

Atomic mass of

$$\text{boron} = (10 \times \frac{20}{100}) + (11 \times \frac{80}{100})$$
$$= (10 \times 0.20) + (11 \times 0.80)$$
$$= 2 + 8.8$$
$$= 10.8 \text{ amu}$$

7.2 MOLECULE AND MOLECULAR MASS

Except noble gases, atoms of most of the elements are found in the combined form with itself or atoms of other elements. It is called as a molecule. **A molecule is a combination of two or more atoms held together by strong chemical forces of attraction, i.e. chemical bonds.**



7.2.1 Classification of molecules

A molecule may contain atoms of the same element or may contain atoms of two or more elements joined in a fixed ratio, in accordance with the law of definite proportions. Thus, a molecule may be an **element or a compound**. If the molecule is made of similar kind of atoms, then it is called **homoatomic molecule**.

The molecule that consist of atoms of different elements is called **heteroatomic molecule.** A compound is a heteroatomic molecule. The number of atoms present in the molecule is called its '**atomicity**'.

Table 7.4 Classification of molecules

Atomicity	No. of atoms present	Name
1	1	Monoatomic
2	2	Diatomic
3	3	Triatomic
>3	>3	Polyatomic

Let us consider oxygen. Oxygen gas exists in two allotropic forms: Oxygen (O_2) and Ozone (O_3). In oxygen molecule, there are two oxygen atoms. So its atomicity is two. Since both the atoms are similar, oxygen (O_2) is a homodiatomic molecule. Other elements

Activity 7.1

Complete the following table by filling the appropriate values /terms

Element	No. of Protons	No. of Neutrons	Mass Number	Stable Isotopes (abundance)	Atomic Mass (amu)
	7			N-14 (99.6 %)	
		8		N-15 (0.4 %)	
Sulphur	**14**		**28**	**S-28 (92.2 %)**	
	14			**S-29 (4.7 %)**	
		16		**S-30 (3.1 %)**	
	17			Cl-35 (75 %)	
	17			Cl-37 (25 %)	

that exist as diatomic molecules are hydrogen (H_2), nitrogen (N_2) and halogens: fluorine (F_2), chlorine (Cl_2), bromine (Br_2) and iodine (I_2).

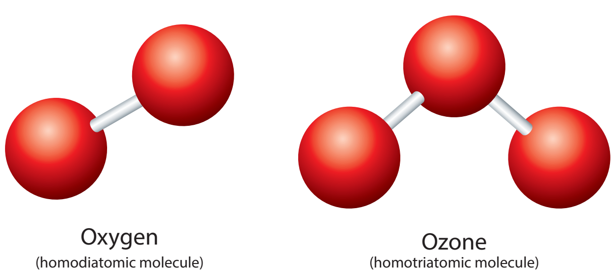


Figure 7.1 Homoatomic molecules

Ozone (O_3) contains three oxygen atoms and hence it is called homotriatomic molecule. If a molecule contains more than three atoms, then it is called **polyatomic molecule**.

Conisder hydrogen chloride. It consists of two atoms, but of different elements, i.e. hydrogen and chlorine. So, its atomicity is two. It is a heterodiatomic molecule. Similarly, the water molecule contains two hydrogen atoms and one oxygen atom. So its atomicity is three. It is a heterotriatomic molecule.

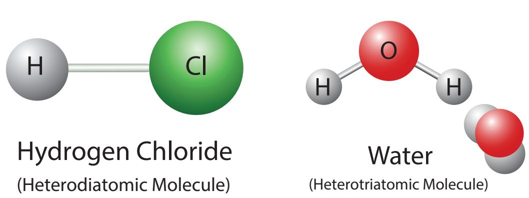


Figure 7.2 Heteroatomic molecules

Activity 7.2

Classify the following molecules based on their atomicity and fill in the table:

Fluorine (F_2), Carbon dioxide (CO_2), Phosphorous (P_4), Sulphur (S_8), Ammonia (NH_3), Hydrogen iodide (HI), Sulphuric Acid (H_2SO_4), Methane (CH_4), Glucose ($C_6H_{12}O_6$), Carbon monoxide (CO)

Molecule	Di - atomic	Tri - atomic	Poly - atomic
Homo			
Hetero			

7.2.2 Relative Molecular Mass (RMM)

As the molecules are made of atoms, they also have their own mass. The mass of the molecule of an element or compound is measured in the C-12 scale and hence called relative molecular mass.

The Relative Molecular Mass of a molecule is the ratio between the mass of one molecule of the substance to $\frac{1}{12^{th}}$ mass of an atom of Carbon -12.

DO YOU KNOW?

Relative Molecular Mass is only a ratio. So, it has no unit. If the molecular mass of a compound is expressed in grams, it is called ***Gram Molecular Mass.***

Gram Molecular Mass of water	=	18 g
Gram Molecular Mass of carbon dioxide	=	44 g
Gram Molecular Mass of ammonia	=	17 g
Gram Molecular Mass of HCl	=	36.5 g

The relative molecular mass is obtained by adding together the relative atomic masses of all the atoms present in a molecule.

Calculation of relative molecular mass – Solved examples:

Example 1: Relative molecular mass of sulphuric acid (H_2SO_4) is calculated as follows: Sulphuric acid conatins 2 atoms of hydrogen, 1 atom of sulphur and 4 atoms of oxygen.

Therefore, Relative molecular mass of sulphuric acid = (2 × mass of hydrogen) + (1 × mass of sulphur) + (4 × mass of oxygen)

$= (2 \times 1) + (1 \times 32) + (4 \times 16)$

$= 98$

i.e., one molecule of H_2SO_4 is 98 times as heavy as $\frac{1}{12^{th}}$ of the mass of a carbon –12.

Example 2: Relative molecular mass of water (H_2O) is calculated as follows: A water molecule is made of 2 atoms of hydrogen and one atom of oxygen.

So, the relative molecular mass of water = (2 × mass of hydrogen) + (1 × mass of oxygen)

$= (2 \times 1) + (1 \times 16)$

$= 18$

i.e., one molecule of H_2O is 18 times as heavy as $\frac{1}{12^{th}}$ of the mass of a carbon –12.

7.3 DIFFERENCE BETWEEN ATOMS AND MOLECULES

Even though atoms are the basic components of molecules, they differ in many aspects when compared to the molecules. Table 7.5 consolidates the major difference between atoms and molecules.

Table 7.5 Difference between atoms and molecules

Atom	Molecule
An atom is the smallest particle of an element	**A molecule is the smallest particle of an element or compound.**
Atom does not exist in free state except in a noble gas	**Molecule exists in free a state**
Except some of noble gas, other atoms are highly reactive	**Molecules are less reactive**
Atom does not have a chemical bond	**Atoms in a molecule are held by chemical bonds**

7.4 MOLE CONCEPT

So far we discussed about matters in terms of individual atoms and molecules. Atomic mass units provide a relative scale for the masses of the elements. Since the atoms have such small masses, no usable scale can be devised to weigh them in the calibrated units of atomic mass units. In any real situation, we deal with macroscopic samples containing enormous number of atoms. Therefore, it is convenient to have a special unit to describe a very large number of atoms. The idea of a 'unit' to denote a particular number of objects is not new. For example, **the pair (2 items) and the dozen (12 items)**, are all familiar units. Chemists measure atoms and molecules in 'moles'. So, you can now understand that 'mole' denotes a number of particles.

In the SI system, the ***mole (mol) is the amount of a substance that contains as many elementary entities (atoms, molecules, or other particles) as there are atoms in exactly 12 g (or 0.012 kg) of the carbon-12 isotope.*** The actual number of atoms in 12 g of carbon-12 is determined experimentally. This is called **Avogadro's Number (N_A),** named after an Italian scientist **Amedeo Avogadro** who proposed its significance. Its value is **6.023×10^{23}**. So one mole of a substance contains **6.023×10^{23}** entities. Thus, 5 moles of oxygen molecules contain $5 \times 6.023 \times 10^{23}$ molecules.

Mole Concept: The study of the collection of particles by using mole as the counting unit, in order to express the mass and volume of such unit particles in a bulk of matter is known as **mole concept**.

The number of moles of a substance can be calculated by various means depending on the data available, as follows:

- Number of moles of molecules.
- Number of moles of atoms.
- Number of moles of a gas (Standard molar volume at STP = 22.4 litre).
- Number of moles of ions.

Note:

STP-Standard Temperature and Pressure(273.15 K,1.00 atm)

Mole of atoms:

One mole of an element contains 6.023×10^{23} atoms and it is equal to its gram atomic mass.

i.e., one mole of oxygen contains 6.023×10^{23} atoms of oxygen and its gram atomic mass is 16 g.

Mole of molecules:

One mole of matter contains 6.023×10^{23} molecules and it is equal to its gram molecular mass.

i.e., one mole of oxygen contains 6.023×10^{23} molecules of oxygen and its gram molecular mass is 32 g.

Molar volume:

One mole of any gas occupies 22.4 litre or 22400 ml at S.T.P. This volume is called as molar volume.

Calculation of number of moles by Different modes

Number of moles

= Mass / Atomic Mass

= Mass / Molecular mass

= Number of Atoms / 6.023×10^{23}

= Number of Molecules / 6.023×10^{23}

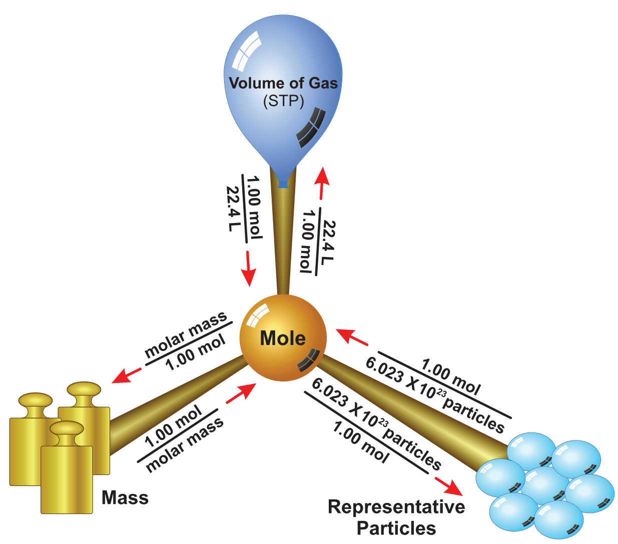


Figure 7.3 Mole concept

7.5 PERCENT COMPOSITION

So for, we were dealing with the number of entities present in a given substance. But many times, the information regarding the percentage of a particular element present in a compound is required.

The percentage composition of a compound represents the mass of each element present in 100 g of the compound.

Let us understand the percentage composition of oxygen and hydrogen by taking the example of H_2O. It can be calculated using the formula

Mass % of an element

$$= \frac{\textit{mass of that element in the compound}}{\textit{molar mass of the compound}} \times 100$$

Now,

molar mass of $H_2O = 2(1) + 16$
$= 18$ g

Mass % of hydrogen $= \frac{2}{18} \times 100$
$= 11.11$ %

Mass % of oxygen $= \frac{16}{18} \times 100$
$= 88.89$ %

This percentage composition is useful to determine the empirical formula and molecular formula.

Example 1: Find the mass percentage composition of methane (CH_4).

Molar mass of $CH_4 = 12 + 4$
$= 16$ g

Mass % of carbon $= \frac{12}{16} \times 100$
$= 75$ %

Mass % of hydrogen $= \frac{4}{16} \times 100$
$= 25$ %

7.6 AVOGADRO HYPOTHESIS

In 1811 Avogadro framed a hypothesis based on the relationship between the number of molecules present in equal volumes of gases in different conditions.

The Avogadro's law states that ***"equal volumes of all gases under similar conditions of temperature and pressure contain equal number of molecules"***

It follows that the volume of any given gas must be proportional to the number of molecules in it. If 'V' is the volume and 'n' is the number of molecules of a gas, then Avogadro law is represented, mathematically, as follows:

$V \propto n$

$V = \text{constant} \times n$

Thus, one litre (1 dm^3) of hydrogen contains the same number of molecules as in one litre of oxygen, i.e. the volume of the gas is directly proportional to the number of molecules of the gas.

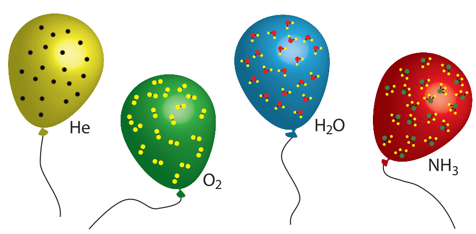


Figure 7.4 Avogadro Hypothesis

Explanation

Let us consider the reaction between hydrogen and chlorine to form hydrogen chloride gas

$H_{2(g)} + Cl_{2(g)} \rightarrow 2\ HCl_{(g)}$

1 vol + 1 vol → 2 volumes

According to Avogadro's law 1 volume of any gas is occupied by "n" number of molecules.

n molecules + n molecules → 2n molecules

if n = 1 then

1molecule + 1 molecule → 2 molecules.

½ molecule + ½ molecule → 1 molecule

1 molecule of hydrogen chloride gas is made up of ½ molecule of hydrogen and ½ molecule of chlorine. Hence, the molecules can be subdivided. This law is in agreement with Dalton's atomic theory.

Activity 7.3

Under same conditions of temperature and pressure if you collect 3 litre of O_2, 5 litre of Cl_2 and 6 litre of H_2,

i. Which has the highest number of molecules?

ii. Which has the lowest number of molecules?

7.7 APPLICATIONS OF AVOGADRO'S LAW

i. It explains Gay-Lussac's law.

ii. It helps in the determination of atomicity of gases.

iii. Molecular formula of gases can be derived using Avogadro's law

iv. It determines the relation between molecular mass and vapour density.

v. It helps to determine gram molar volume of all gases (i.e, 22.4 litre at S.T.P)

7.8 RELATIONSHIP BETWEEN VAPOUR DENSITY AND RELATIVE MOLECULAR MASS

i. Relative molecular mass: (Hydrogen scale)

The Relative Molecular Mass of a gas or vapour is the ratio between the mass of one molecule of the gas or vapour to mass of one atom of Hydrogen.

ii. Vapour Density:

Vapour density is the ratio of the mass of a certain volume of a gas or vapour, to the mass of an equal volume of hydrogen, measured under the same conditions of temperature and pressure.

Vapour Density (V.D.)

$$= \frac{\text{Mass of a given volume of gas or vapour at S.T.P.}}{\text{Mass of the same volume of hydrogen}}$$

According to Avogadro's law, equal volumes of all gases contain equal number of molecules.

Thus, let the number of molecules in one volume = n, then

V.D. at S.T.P

$$= \frac{\text{Mass of 'n' molecules of a gas or vapour at S.T.P.}}{\text{Mass of 'n' molecules of hydrogen}}$$

Cancelling 'n' which is common, you get

V.D.

$$= \frac{\text{Mass of 1 molecule of a gas or vapour at S.T.P.}}{\text{Mass of 1 molecules of hydrogen}}$$

However, since hydrogen is diatomic

V.D.

$$= \frac{\text{Mass of 1 molecule of a gas or vapour at S.T.P.}}{\text{Mass of 2 atoms of hydrogen}}$$

When you compare the formula of vapour density with relative molecular mass, they can be represented as

V.D.

$$= \frac{\text{Mass of 1 molecule of a gas or vapour at S.T.P.}}{2 \times \text{Mass of 1 atom of hydrogen}}$$

(Eqn 7.1)

Relative molecular mass (hydrogen scale) =

$$\frac{\text{Mass of 1 molecule of a gas or vapour at STP}}{\text{Mass of 1 atom of hydrogen}}$$

(Eqn 7.2)

You can therefore substitute the above equation to an Eqn 7.1 and arrive at the following formula

$$\text{V.D.} = \frac{\text{Relative molecular mass}}{2}$$

Now on cross multiplication, you have

2 × vapour density = Relative molecular mass of a gas

(Or)

Relative molecular mass = 2 × Vapour density

7.9 SOLVED PROBLEMS

I. Calculation of molar mass

Calculate the gram molar mass of the following.

1) H_2O 2) CO_2 3) $Ca_3(PO_4)_2$

Solution:

1) H_2O

Atomic masses of H = 1, O = 16

10th_Science_Unit-7.indd 99 21-02-2019 18:38:25

Gram molar mass of H_2O

$= (1 \times 2) + (16 \times 1)$

$= 2 + 16$

Gram molar mass of H_2O = 18 g

2) CO_2

Atomic masses of C = 12, O = 16

Gram molar mass of CO_2

$= (12 \times 1) + (16 \times 2)$

$= 12 + 32$

Gram molar mass of CO_2 = 44 g

3) $Ca_3(PO_4)_2$

Atomic masses of Ca = 40, P = 30, O = 16.

Gram molar mass of $Ca_3(PO_4)_2$

$= (40 \times 3) + [30 + (16 \times 4)] \times 2$

$= 120 + (94 \times 2)$

$= 120 + 188$

Gram molar mass of $Ca_3(PO_4)_2$ = 308 g

II. Calculation based on number of moles from mass and volume

1) Calculate the number of moles in 46 g of sodium?

$$\text{Number of moles} = \frac{\text{Mass of the element}}{\text{Atomic mass of the element}}$$

$= 46 / 23$

$= 2$ moles of sodium

2) 5.6 litre of oxygen at S.T.P

$$\text{Number moles} = \frac{\text{Given volume of } O_2 \text{ at S.T.P}}{\text{Molar volume at S.T.P}}$$

$$\text{Number of moles of oxygen} = \frac{5.6}{22.4}$$

$= 0.25$ mole of oxygen

3) Calculate the number of moles of a sample that contains 12.046×10^{23} atoms of iron ?

$$\text{Number of moles} = \frac{\text{Number of atoms of iron}}{\text{Avogadro's number}}$$

$= 12.046 \times 10^{23} / 6.023 \times 10^{23}$

$= 2$ moles of iron

III. Calculation of mass from mole

Calculate the mass of the following

1) 0.3 mole of aluminium (Atomic mass of Al = 27)

$$\text{Number of moles} = \frac{\text{Mass of Al}}{\text{Atomic mass of Al}}$$

Mass = No. of moles × atomic mass

So, mass of Al = 0.3×27

$= 8.1$ g

2) 2.24 litre of SO_2 gas at S.T.P

Molecular mass of $SO_2 = 32 + (16 \times 2)$

$= 32 + 32 = 64$

$$\text{Number of moles of } SO_2 = \frac{\text{Given volume of } SO_2 \text{ at S.T.P}}{\text{Molar volume } SO_2 \text{ at S.T.P}}$$

$$\text{Number of moles of } SO_2 = \frac{2.24}{22.4}$$

$= 0.1$ mole

$$\text{Number of moles} = \frac{\text{Mass}}{\text{Molecular mass}}$$

Mass = No. of moles × molecular mass

Mass = 0.1×64

Mass of SO_2 = 6.4 g

3) 1.51×10^{23} molecules of water

Molecular mass of H_2O = 18

$$\text{Number of moles} = \frac{\text{Number of molecules of water}}{\text{Avogadro's number}}$$

$= 1.51 \times 10^{23} / 6.023 \times 10^{23}$

$= 1 / 4$

$= 0.25$ mole

$$\text{Number of moles} = \frac{\text{Mass}}{\text{Molecular mass}}$$

0.25 = mass / 18

Mass = 0.25×18

Mass = 4.5 g

4) 5×10^{23} molecules of glucose ?

Molecular mass of glucose = 180

$$\text{Mass of glucose} = \frac{\text{Molecular mass} \times \text{number of particles}}{\text{Avogadro's number}}$$

$= (180 \times 5 \times 10^{23}) / 6.023 \times 10^{23}$

$= 149.43$ g

IV. Calculation based on number of atoms/ molecules.

1) Calculate the number of molecules in 11.2 litre of CO_2 at S.T.P

$$\text{Number of moles of } CO_2 = \frac{\text{Volume at S.T.P}}{\text{Molar volume}}$$

$= 11.2 / 22.4$

$= 0.5$ mole

Number of molecules of CO_2 = number of moles of CO_2 × Avogadro's number

$= 0.5 \times 6.023 \times 10^{23}$

$= 3.011 \times 10^{23}$ molecules of CO_2

2) Calculate the number of atoms present in 1 gram of gold (Atomic mass of Au = 198)

$$\text{Number of atoms of Au} = \frac{\text{Mass of Au} \times \text{Avogadro's number}}{\text{Atomic mass of Au}}$$

$$\text{Number of atoms of Au} = \frac{1}{198} \times 6.023 \times 10^{23}$$

Number of atoms of Au = 3.042×10^{21} g

3) Calculate the number of molecules in 54 gm of H_2O?

$$\text{Number of molecules} = \frac{(\text{Avogadro number} \times \text{Given mass})}{\text{Gram molecular mass}}$$

Number of molecules

of water = $6.023 \times 10^{23} \times 54 \;/\; 18$

$= 18.069 \times 10^{23}$ molecules

4) Calculate the number of atoms of oxygen and carbon in 5 moles of CO_2.

- 1 mole of CO_2 contains 2 moles of oxygen
- 5 moles of CO_2 contain 10 moles of oxygen

Number of atoms of oxygen = Number of moles of oxygen × Avogadro's number

$= 10 \times 6.023 \times 10^{23}$

$= 6.023 \times 10^{24}$ atoms of Oxygen

- 1 mole of CO_2 contains 1 mole of carbon
- 5 moles of CO_2 contains 5 moles of carbon

No. of atoms of carbon = No.of moles of carbon × Avogadro's number

$= 5 \times 6.023 \times 10^{23}$

$= 3.011 \times 10^{24}$ atoms of Carbon

V. Calculation based on molar volume

Calculate the volume occupied by:

1) 2.5 mole of CO_2 at S.T.P

$$\text{Number of moles of } CO_2 = \frac{\text{Given volume at S.T.P}}{\text{Molar volume at S.T.P}}$$

$$2.5 \text{ mole of } CO_2 = \frac{\text{Volume of } CO_2 \text{ at S.T.P}}{22.4}$$

Volume of CO_2 at S.T.P = 22.4×2.5

= 56 litres.

2) 3.011×10^{23} of ammonia gas molecules

$$\text{Number of moles} = \frac{\text{Number of molecules}}{\text{Avogadro's number}}$$

$= 3.011 \times 10^{23} / 6.023 \times 10^{23}$

= 2 moles

Volume occupied by NH_3

= number of moles × molar volume

$= 2 \times 22.4$

= 44.8 litres at S.T.P

3) 14 g nitrogen gas

Number of moles = 14 / 28

= 0.5 mole

Volume occupied by N_2 at S.T.P

= no. of moles × molar volume

$= 0.5 \times 22.4$

= 11.2 litres.

VI. Calculation based on % composition

Calculate % of S in H_2SO_4

Molar mass of H_2SO_4

$= (1 \times 2) + (32 \times 1) + (16 \times 4)$

$= 2 + 32 + 64$

$= 98$ g

$$\% \text{ of S in } H_2SO_4 = \frac{\text{Mass of sulphur}}{\text{Molar mass of } H_2SO_4} \times 100$$

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

$= 32.65\ \%$

Points to Remember

- Two or more forms of an element having the same atomic number, but different mass number are called Isotopes ($_{17}Cl^{35}$, $_{17}Cl^{37}$).
- Atoms of different elements having the same mass number, but different atomic numbers are called Isobars ($_{18}Ar^{40}$, $_{20}Ca^{40}$).
- Atoms of different elements having the same number of neutrons, but different atomic number and different mass number are called Isotones ($_{6}C^{13}$, $_{7}N^{14}$).
- Relative atomic mass of an element is the ratio between the mass of one atom of the element to 1/12th of the mass of the atom of carbon -12.
- Average atomic mass of an element is calculated by adding the masses of its isotopes, each multiplied by their natural abundance on the Earth.
- Relative molecular mass of a molecule is the ratio between the mass of one molecule of the substance to 1/12th of the mass of the atom of carbon – 12.
- The Avogadro's law states that "equal volumes of all gases under similar conditions of temperature and pressure contain equal number of molecules".
- The vapour density is defined as "the ratio between the masses of equal volumes of a gas (or a vapour) and hydrogen under the same condition".
- Atomicity of a monoatomic element = Molecular mass / Atomic Mass.
- Molecular mass = 2 × Vapour density.

DLRFYB

TEXTBOOK EVALUATION

I. Choose the best answer.

1. Which of the following has the smallest mass?
   a. 6.023×10^{23} atoms of He
   b. 1 atom of He
   c. 2 g of He
   d. 1 mole atoms of He

2. Which of the following is a triatomic molecule?
   a. Glucose b. Helium
   c. Carbon dioxide d. Hydrogen

3. The volume occupied by 4.4 g of CO_2 at S.T.P
   a. 22.4 litre b. 2.24 litre
   c. 0.24 litre d. 0.1 litre

4. Mass of 1 mole of Nitrogen atom is
   a. 28 amu b. 14 amu
   c. 28 g d. 14 g

5. Which of the following represents 1 amu?
   a. Mass of a C – 12 atom
   b. Mass of a hydrogen atom
   c. $1/12^{th}$ of the mass of a C – 12 atom
   d. Mass of O – 16 atom

6. Which of the following statement is incorrect?
   a. One gram of C – 12 contains Avogadro's number of atoms.
   b. One mole of oxygen gas contains Avogadro's number of molecules.
   c. One mole of hydrogen gas contains Avogadro's number of atoms.
   d. One mole of electrons stands for 6.023×10^{23} electrons.

7. The volume occupied by 1 mole of a diatomic gas at S.T.P is

a. 11.2 litre	b. 5.6 litre
c. 22.4 litre	d. 44.8 litre

8. In the nucleus of ${}_{20}Ca^{40}$, there are
   a. 20 protons and 40 neutrons
   b. 20 protons and 20 neutrons
   c. 20 protons and 40 electrons
   d. 40 protons and 20 electrons

9. The gram molecular mass of oxygen molecule is

a. 16 g	b. 18 g
c. 32 g	d. 17 g

10. 1 mole of any substance contains _____ molecules.

a. 6.023×10^{23}	b. 6.023×10^{-23}
c. 3.0115×10^{23}	d. 12.046×10^{23}

II. Fill in the blanks

1. Atoms of different elements having ________ mass number, but _________ atomic numbers are called isobars.
2. Atoms of different elements having same number of ____________ are called isotones.
3. Atoms of one element can be transmuted into atoms of other element by _________
4. The sum of the numbers of protons and neutrons of an atom is called its ___________
5. Relative atomic mass is otherwise known as ___________
6. The average atomic mass of hydrogen is ____________ amu.
7. If a molecule is made of similar kind of atoms, then it is called _____________ atomic molecule.
8. The number of atoms present in a molecule is called its _____________
9. One mole of any gas occupies _________ ml at S.T.P
10 Atomicity of phosphorous is ____________

III. Match the following

1.	8 g of O_2	-	4 moles
2.	4 g of H_2	-	0.25 moles
3.	52 g of He	-	2 moles
4.	112 g of N_2	-	0.5 moles
5.	35.5 g of Cl_2	-	13 moles

IV. True or False: (If false give the correct statement)

1. Two elements sometimes can form more than one compound.
2. Noble gases are Diatomic
3. The gram atomic mass of an element has no unit
4. 1 mole of Gold and Silver contain same number of atoms
5. Molar mass of CO_2 is 42g.

V. Assertion and Reason:

Answer the following questions using the data given below:

i) A and R are correct, R explains the A.

ii) A is correct, R is wrong.

iii) A is wrong, R is correct.

iv) A and R are correct, R doesn't explains A.

1. Assertion: Atomic mass of aluminium is 27

Reason: An atom of aluminium is 27 times heavier than 1/12th of the mass of the C – 12 atom.

2. **Assertion:** The Relative Molecular Mass of Chlorine is 35.5 a.m.u.

   Reason: The natural abundance of Chlorine isotopes are not equal.

VI. Short answer questions

1. Define: Relative atomic mass.
2. Write the different types of isotopes of oxygen and its percentage abundance.
3. Define: Atomicity
4. Give any two examples for heterodiatomic molecules.
5. What is Molar volume of a gas?
6. Find the percentage of nitrogen in ammonia.

VII. Long answer questions

1. Calculate the number of water molecule present in one drop of water which weighs 0.18 g.
2. $N_2 + 3H_2 \rightarrow 2NH_3$

   (The atomic mass of nitrogen is 14, and that of hydrogen is 1)

   1 mole of nitrogen (________g) +
   3 moles of hydrogen (__________ g) →

   2 moles of ammonia (__________ g)
3. Calculate the number of moles in

   i) 27g of Al   ii) 1.51×10^{23} molecules of NH_4Cl
4. Give the salient features of "Modern atomic theory".
5. Derive the relationship between Relative molecular mass and Vapour density.

VIII. HOT question

1. Calculate carbonate is decomposed on heating in the following reaction

$$CaCO_3 \rightarrow CaO + CO_2$$

   i. How many moles of Calcium carbonate are involved in this reaction?

   ii. Calculate the gram molecular mass of calcium carbonate involved in this reaction

   iii. How many moles of CO_2 are there in this equation?

IX. Solve the following problems

1. How many grams are there in the following?

   i. 2 moles of hydrogen molecule, H_2

   ii. 3 moles of chlorine molecule, Cl_2

   iii. 5 moles of sulphur molecule, S_8

   iv. 4 moles of phosphorous molecule, P_4
2. Calculate the % of each element in calcium carbonate. (Atomic mass: C-12, O-16, Ca -40)
3. Calculate the % of oxygen in $Al_2(SO_4)_3$. (Atomic mass: Al-12, O-16, S -32)
4. Calculate the % relative abundance of B-10 and B-11, if its average atomic mass is 10.804 amu.

REFERENCE BOOKS

1) Petrucci, Ralph H et.al. General Chemistry: Principles & Modern Applications (9th Edition). Upper Saddle River, NJ: Pearson Prentice Hall, 2007. Print.

2) Raymond Chang. (2010). Chemistry. New York, NY: The Tata McGraw Hill Companies. Inc.

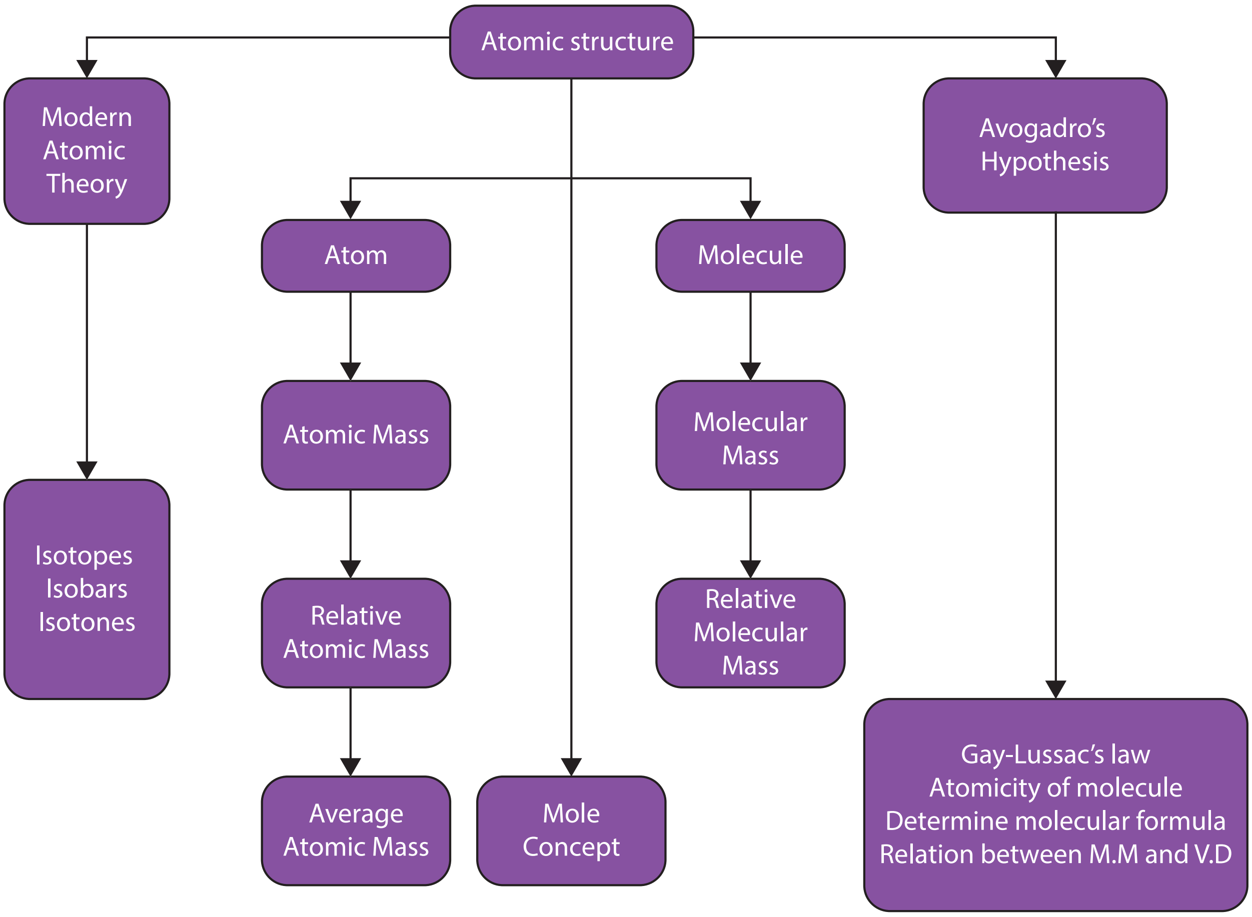
3) Julia Burdge. (2011). Chemistry. New York, NY: The Tata McGraw Hill Companies.Inc.

INTERNET RESOURCES

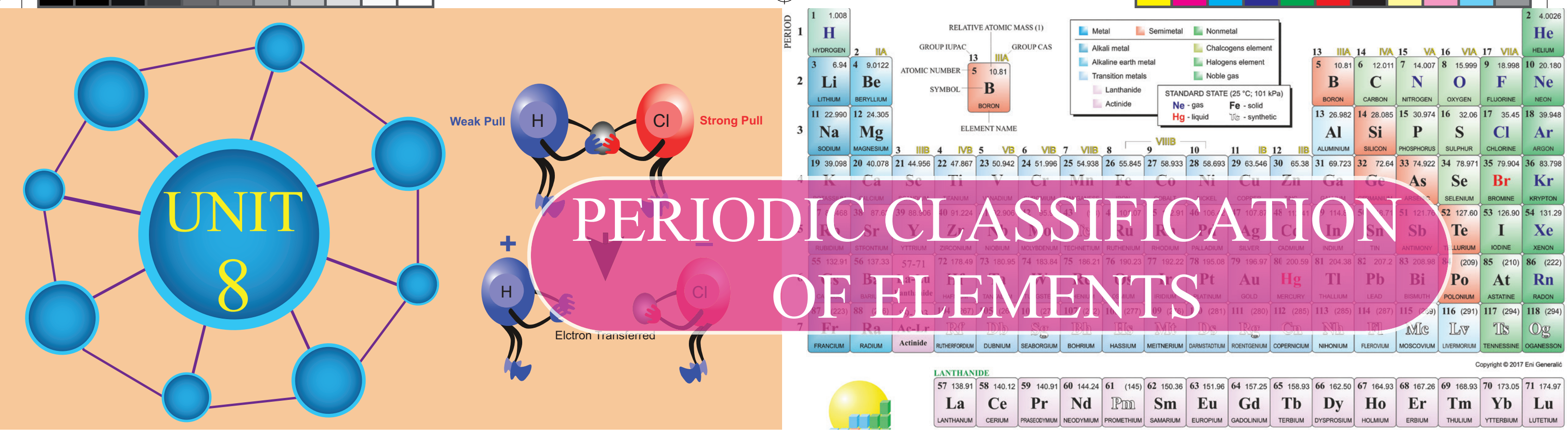
https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookCHEM1.html

https://www.toppr.com/guides/chemistry/atoms-and-molecules/

CONCEPT MAP



Atomic structure
Modern Atomic Theory
Avogadro's Hypothesis
Atom
Molecule
Atomic Mass
Molecular Mass
Isotopes
Isobars
Isotones
Relative Atomic Mass
Relative Molecular Mass
Gay-Lussac's law
Atomicity of molecule
Determine molecular formula
Relation between M.M and V.D
Average Atomic Mass
Mole Concept



PERIODIC CLASSIFICATION OF ELEMENTS

Learning Objectives

After a thorough perusal of this unit, the students will be able to:

- recognize the basis of the modern periodic law and its development.
- list the features of groups and periods of the modern periodic table.
- explain the trend in periodic properties along the periods and groups.
- distinguish between ores and minerals .
- list out the types of separation of impurities from the ores.
- recall the various places of occurrences of minerals in the state of Tamil Nadu.
- put forth the properties of metals.
- identify the stages involved in metallurgical processes.
- think scientifically on alloys and their types.
- develop an idea on amalgam.
- understand the reason for corrosion and the methods of its prevention.

E2AAZM

INTRODUCTION

The eighteenth and nineteenth centuries witnessed a rapid development in chemistry in all spheres of scientific activities. By 1860, scientists had already discovered 60 elements and determined their atomic masses. They noticed that some elements had similar properties and hence arranged them into groups. During this period, several new elements were discovered. These elements were found to have different properties. It was realized that instead of studying the properties of all these elements individually, it would be more convenient to divide them into groups and periods in such a way that each group contained a certain number of elements **(like an array of fruits and vegetables showing orderliness)** with similar properties and periods showing a regular gradation. So, scientists made several attempts to arrange elements in a logical way. You have studied about all these early attempts of arrangement of elements in standard IX. In continuation of the knowledge gained in the topic **periodic classification of elements** in standard IX with earlier concepts and their subsequent deliberations, you get set to go ahead with the higher order of thinking to enhance your knowledge on the properties of elements.

8.1 MODERN PERIODIC LAW

Mendeleev's periodic table had some discrepancies, which were difficult to overcome. For example, the atomic mass of argon (39.95 amu) is greater than that of potassium (39.10 amu), but argon comes before potassium in the periodic table. If elements were arranged solely according to increasing atomic mass, argon would appear in the position occupied by potassium in our modern periodic table (see in Figure 8.1). No chemist would place argon, a gas with no tendency to react, in the same group as lithium and sodium,which are two highly reactive metals. This kind of discrepancies suggested that some fundamental property other than atomic mass must be the basis of periodicity. The fundamental property turned out to be the number of protons in an atom's nucleus, something that could not have been known by Mendeleev and his contemporaries.

Henry Moseley, a British scientist in 1912, discovered a new property of elements called atomic number, which provided a better basis for the periodic arrangement of the elements. It is a well-known fact that atomic number of an element is equal to the number of protons or the number of electrons present in the neutral atom of an element. The periodic law was, therefore, modified to frame a **modern periodic law,** which states that

"The physical and chemical properties of the elements are the periodic functions of their atomic numbers".

8.2 MODERN PERIODIC TABLE

With reference to the modern periodic law, the elements were arranged in the increasing order of their atomic numbers to form the modern periodic table. **The modern periodic table is a tabular arrangement of elements in rows and columns, highlighting the regular repetition of properties of the elements.** Figure 8.1 shows the modern periodic table of 118 elements discovered so far.

As you have studied the features of the modern periodic table in standard IX, here let us confine to the study of the features of periods and groups.

8.2.1 Features of Periods

- The **horizontal rows are called periods**. There are **seven** periods in the periodic table.
- **First period** (Atomic number 1 and 2): This is the shortest period. It contains only two elements (Hydrogen and Helium).
- **Second period** (Atomic number 3 to 10): This is a short period. It contains eight elements (Lithium to Neon).
- **Third period** (Atomic number 11 to 18): This is also a short period. It contains eight elements (Sodium to Argon).
- **Fourth period** (Atomic number 19 to 36): This is a long period. It contains eighteen elements (Potassium to Krypton). This includes 8 normal elements and 10 transition elements.
- **Fifth period** (Atomic number 37 to 54): This is also a long period. It contains 18 elements (Rubidium to Xenon). This includes 8 normal elements and 10 transition elements.
- **Sixth period** (Atomic number 55 to 86): This is the longest period. It contains 32 elements (Caesium to Radon). This includes 8 normal elements, 10 transition elements and 14 inner transition elements (Lanthanides).
- **Seventh period** (Atomic number 87 to 118): Like the sixth period, this period also accommodates 32 elements. Recently 4 elements have been included by IUPAC.

PERIODIC TABLE OF THE ELEMENTS

Key: GROUP IUPAC 13, GROUP CAS IIIA, ATOMIC NUMBER 5, RELATIVE ATOMIC MASS (1) 10.81, SYMBOL B, ELEMENT NAME BORON

Metal | Semimetal | Nonmetal

Alkali metal | Alkaline earth metal | Transition metals | Lanthanide | Actinide

Chalcogens element | Halogens element | Noble gas

STANDARD STATE (25 °C; 101 kPa): Ne - gas; Hg - liquid; Fe - solid; Tc - synthetic

PERIOD	GROUP 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H 1.008 HYDROGEN																	2 He 4.0026 HELIUM
2	3 Li 6.94 LITHIUM	4 Be 9.0122 BERYLLIUM											5 B 10.81 BORON	6 C 12.011 CARBON	7 N 14.007 NITROGEN	8 O 15.999 OXYGEN	9 F 18.998 FLUORINE	10 Ne 20.180 NEON
3	11 Na 22.990 SODIUM	12 Mg 24.305 MAGNESIUM											13 Al 26.982 ALUMINIUM	14 Si 28.085 SILICON	15 P 30.974 PHOSPHORUS	16 S 32.06 SULPHUR	17 Cl 35.45 CHLORINE	18 Ar 39.948 ARGON
4	19 K 39.098 POTASSIUM	20 Ca 40.078 CALCIUM	21 Sc 44.956 SCANDIUM	22 Ti 47.867 TITANIUM	23 V 50.942 VANADIUM	24 Cr 51.996 CHROMIUM	25 Mn 54.938 MANGANESE	26 Fe 55.845 IRON	27 Co 58.933 COBALT	28 Ni 58.693 NICKEL	29 Cu 63.546 COPPER	30 Zn 65.38 ZINC	31 Ga 69.723 GALLIUM	32 Ge 72.64 GERMANIUM	33 As 74.922 ARSENIC	34 Se 78.971 SELENIUM	35 Br 79.904 BROMINE	36 Kr 83.798 KRYPTON
5	37 Rb 85.468 RUBIDIUM	38 Sr 87.62 STRONTIUM	39 Y 88.906 YTTRIUM	40 Zr 91.224 ZIRCONIUM	41 Nb 92.906 NIOBIUM	42 Mo 95.95 MOLYBDENUM	43 Tc (98) TECHNETIUM	44 Ru 101.07 RUTHENIUM	45 Rh 102.91 RHODIUM	46 Pd 106.42 PALLADIUM	47 Ag 107.87 SILVER	48 Cd 112.41 CADMIUM	49 In 114.82 INDIUM	50 Sn 118.71 TIN	51 Sb 121.76 ANTIMONY	52 Te 127.60 TELLURIUM	53 I 126.90 IODINE	54 Xe 131.29 XENON
6	55 Cs 132.91 CAESIUM	56 Ba 137.33 BARIUM	57-71 La-Lu Lanthanide	72 Hf 178.49 HAFNIUM	73 Ta 180.95 TANTALUM	74 W 183.84 TUNGSTEN	75 Re 186.21 RHENIUM	76 Os 190.23 OSMIUM	77 Ir 192.22 IRIDIUM	78 Pt 195.08 PLATINUM	79 Au 196.97 GOLD	80 Hg 200.59 MERCURY	81 Tl 204.38 THALLIUM	82 Pb 207.2 LEAD	83 Bi 208.98 BISMUTH	84 Po (209) POLONIUM	85 At (210) ASTATINE	86 Rn (222) RADON
7	87 Fr (223) FRANCIUM	88 Ra (226) RADIUM	89-103 Ac-Lr Actinide	104 Rf (267) RUTHERFORDIUM	105 Db (268) DUBNIUM	106 Sg (271) SEABORGIUM	107 Bh (272) BOHRIUM	108 Hs (277) HASSIUM	109 Mt (276) MEITNERIUM	110 Ds (281) DARMSTADTIUM	111 Rg (280) ROENTGENIUM	112 Cn (285) COPERNICIUM	113 Nh (285) NIHONIUM	114 Fl (287) FLEROVIUM	115 Mc (289) MOSCOVIUM	116 Lv (291) LIVERMORIUM	117 Ts (294) TENNESSINE	118 Og (294) OGANESSON

LANTHANIDE	57 La 138.91 LANTHANUM	58 Ce 140.12 CERIUM	59 Pr 140.91 PRASEODYMIUM	60 Nd 144.24 NEODYMIUM	61 Pm (145) PROMETHIUM	62 Sm 150.36 SAMARIUM	63 Eu 151.96 EUROPIUM	64 Gd 157.25 GADOLINIUM	65 Tb 158.93 TERBIUM	66 Dy 162.50 DYSPROSIUM	67 Ho 164.93 HOLMIUM	68 Er 167.26 ERBIUM	69 Tm 168.93 THULIUM	70 Yb 173.05 YTTERBIUM	71 Lu 174.97 LUTETIUM
ACTINIDE	89 Ac (227) ACTINIUM	90 Th 232.04 THORIUM	91 Pa 231.04 PROTACTINIUM	92 U 238.03 URANIUM	93 Np (237) NEPTUNIUM	94 Pu (244) PLUTONIUM	95 Am (243) AMERICIUM	96 Cm (247) CURIUM	97 Bk (247) BERKELIUM	98 Cf (251) CALIFORNIUM	99 Es (252) EINSTEINIUM	100 Fm (257) FERMIUM	101 Md (258) MENDELEVIUM	102 No (259) NOBELIUM	103 Lr (262) LAWRENCIUM

www.periodni.com

(1) Atomic weights of the elements 2013, Pure Appl. Chem., **88**, 265-291 (2016)

Figure 8.1 Modern Periodic Table

8.2.2 Features of Groups

- The vertical columns in the periodic table starting from top to bottom are called **groups.** There are **18 groups** in the periodic table.
- Based on the common characteristics of elements in each group, they can be grouped as various families.

Group Number	Family
1	Alkali Metals
2	Alkaline earth metals
3 to 12	Transition metals
13	Boron Family
14	Carbon Family
15	Nitrogen Family
16	Oxygen Family (or) Chalcogen family
17	Halogens
18	Noble gases

- The Lanthanides and Actinides, which form part of Group 3 are called **inner transition elements**.
- Except 'group 0', all the elements present in each group have the same number of electrons in their valence shell and thus have the same valency. For example, all the elements of group 1 have one electron in their valence shells ($1s^1$). So, the valency of all the alkali metals is ‘1’.
- As the elements present in a group have identical valence shell electronic configurations, they possess similar chemical properties.
- The physical properties of the elements in a group such as melting point, boiling point and density vary gradually.
- The atoms of the 'group 0' elements have stable electronic configuration in their valence shells and hence they are unreactive.

8.3 PERIODIC TRENDS IN PROPERTIES

EGJ9ZB

The electronic configurations of elements help us to explain the periodic recurrence of physical and chemical properties. Anything which repeats itself after a regular interval is called **periodic** and this behaviour is called **periodicity.** Some of the atomic properties of the elements are periodic.

Properties such as atomic radius, ionic radius, ionisation energy, electronegativity, electron affinity, show a regular periodicity and hence they are called **periodic properties**. The main significance of the modern periodic table is that it gives a clear understanding of the general properties and trends within a group or a period to predict with considerable accuracy, the properties of any element, even though that element may be unfamiliar to us. Let us discuss the periodic trend of some of the properties.

8.3.1 Atomic Radius

Atomic radius of an atom is defined as the distance between the centre of its nucleus and the outermost shell containing the valence electron. Direct measurement of the radius of an isolated atom is not possible. Except for noble gases, usually the atomic radius is referred to as **covalent radius** or **metallic radius** depending on the nature of the bonding between the concerned atoms. Atomic radius in metal atoms is known as **metallic radius.** It is defined as **half the distance between the nuclei of adjacent metal atoms** (Figure 8.2

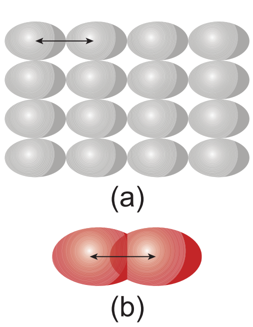


Figure 8.2
(a) Metallic Radius
(b) Covalent Radius

(a)). In non-metallic elements, their atomic radius is known as **Covalent radius.** It is defined as **half the distance between the nuclei of two covalently bonded atoms of the same element in a molecule** (Figure 8.2 (b)). For example, let us consider H_2 molecule. The distance between the two hydrogen nuclei of the molecule is 0.74 Å. So its covalent radius is 0.74/2 = 0.37 Å.

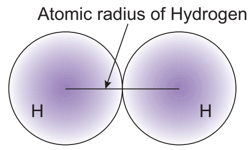


Figure 8.3 Atomic radius

When you look at the variation of the atomic radii in the periodic table, there are two distinct trends. Along the period, from left to right, the atomic radius of the elements decreases whereas along the groups, from the top to bottom, the atomic radius increases. The increase, down a group, is due to the increase in the valence shell number down the group. As the shell number increases, the distance between the valence shell and the nucleus increases. In contrast, when you observe along the period, the shell number remains the same but the number of protons (i.e. atomic number) increases. More and more positive charges impose a strong attraction over the electrons and thus the electron cloud shrinks towards the nucleus, which results in the decrease in the atomic size. Figure 8.4 shows how the atomic radius decreases from lithium to boron.

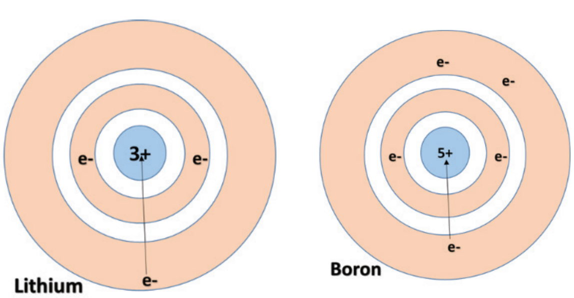


Figure 8.4 Variation of atomic radius

8.3.2 Ionic Radii

It is defined as the distance from the centre of the nucleus of the ion upto the point where it exerts its influence on the electron cloud of the ion. You know that ions are formed when an atom lose or gain electrons. When a neutral atom loses an electron, it becomes a positively charged ion called **cation,** whereas the gain of an electron by a neutral atom forms a negatively charged ion called **anion.** The size of the ions is important to determine their behaviours in solutions and the structure of ionic solids. The size of a cation is always smaller than its corresponding neutral atom. But, the anion is larger than its neutral atom.

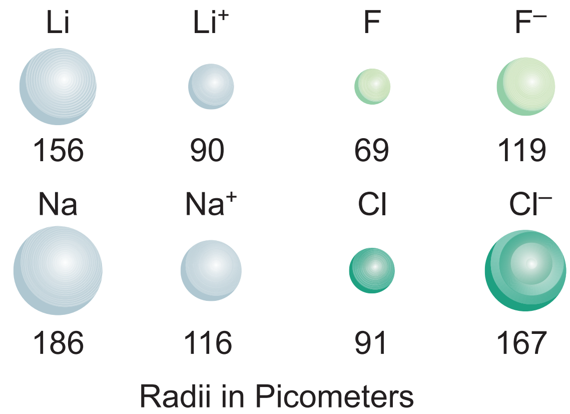


Figure 8.5 Relative ionic radii of cation and anion

For instance, lithium and sodium lose the single electron from their outermost energy level to form cations. The ions so formed are smaller because the remaining electrons are at a inner cells and attracted more strongly by the nucleus. Fluorine and chlorine become negative ions by gaining an electron. When electrons are added, the charge on the nucleus is not great enough to hold the increased number of electrons as closely as it holds the electrons in the neutral atom. So, **as seen in atomic radius, ionic radii also decrease along the period from left to right and increase down the group.**

8.3.3 Ionisation Energy

Ionisation energy is the minimum energy required to remove an electron from a gaseous atom in its ground state to form a cation. It is otherwise called **ionisation enthalpy.** It is measured in kJ/mol. Higher the ionisation energy, it is more difficult to remove the electron.

As the atomic size decreases from left to right in a period, more energy is required to remove the electrons. **So, the ionisation energy increases along the period.** But, down the group, the atomic size increases and hence the valence electrons are loosely bound. They require relatively less energy for the removal. Thus, **ionisation energy decreases down the group in the periodic table.**

Note: As the positive charge increases the size of the cation decreases
As the negative charge increases the size of the anion increases

8.3.4 Electron Affinity

Electron affinity is the amount of energy released when a gaseous atom gains an electron to form its anion. It is also measured in kJ/mol and represented by the following equation:

$$A_{(g)} + e^- \rightarrow A^-_{(g)} + \text{Energy}$$
$$Cl_{(g)} + e^- \rightarrow Cl^-_{(g)} + \text{energy}$$

Like ionisation energy, electron affinity also increases from left to right in a period and decreases from top to bottom in a group.

More to Know

Noble gases show no tendency to accept electrons because the outer s and p orbitals of noble gases are completely filled. No more electrons can be added to them and hence their electron affinities are zero.

8.3.5 Electronegativity

Electronegativity of an element is the measure of the tendency of its atom to attract the shared pair of electrons towards itself in a covalent bond. Let us consider HCl molecule. Both the hydrogen and chlorine atoms share one electron each to form the covalent bond between them. chlorine atom has a higher electronegativity and hence it pulls the shared electrons towards itself more strongly than hydrogen. Thus, when the bond breaks, the bonding electrons are left with chlorine forming H^+ and Cl^- ions. It is represented, diagrammatically, as shown below:

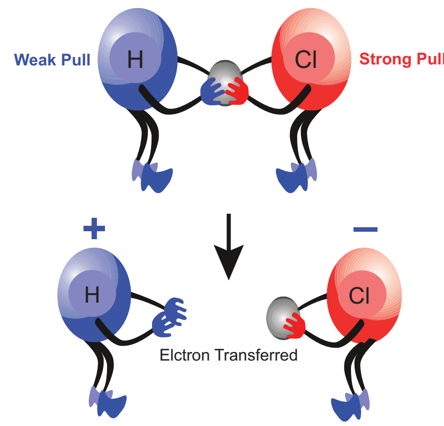


Figure 8.6 Relative electronegativity of H and Cl

Electronegativity is based on various experimental data such as bond energy, ionization potential, electron affinity, etc.

Pauling scale is the widely used scale to determine the electronegativity, which in turn predicts the nature of bonding (ionic or covalent) between the atoms in a molecule.

Electronegativity of some of the elements are given below

F = 4.0, Cl = 3.0, Br = 2.8, I = 2.5, H = 2.1, Na = 1

If the difference in electronegativity between two elements is 1.7, the bond has 50% ionic character and 50% covalent character.

If the difference is less than 1.7, the bond is considered to be covalent.

If the difference is greater than 1.7, the bond is considered to be ionic.

Along the period, from left to right in the periodic table, the electronegativity increases because of the increase in the nuclear charge which in turn attracts the electrons more strongly. On moving down a group, the electronegativity of the elements decreases because of the increased number of energy levels.

Periodic Property	In Periods	In Groups
Atomic radius	Decreases	Increases
Ionic radius	Decreases	Increases
Ionisation energy	Increases	Decreases
Electron affinity	Increases	Decreases
Electronegativity	Increases	Decreases

Test yourself

Predict the nature of the bond in the following molecules.

(i) NaCl (ii) NaBr (iii) NaI

(iv) NaF (v) NaH

8.4 METALLURGY

Human life is associated with various metals. We use metals in our day to day activities. It is the utmost need to have some metals like sodium, potassium, calcium, iron, etc. in the human body. Deficiency of these metals affects the metabolic activities thereby causing diseases. So, metals play a vital role in our life. In this section, let us discuss how metals are obtained from various sources by the process of metallurgy.

Metallurgy is a science of extracting metals from their ores and modifying the metals into alloys for various uses, based on their physical and chemical properties and their structural arrangement of atoms. A metallurgical process involve three main steps as follows:

(i) **Concentration or Separation of the ore:** It is the process of removal of impuries from the ore.

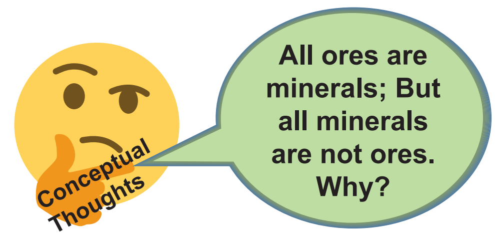
(ii) **Production of the metal:** It is the convertion of the ore into metal.

(iii) **Refining of the metal:** It is the process of purification of the metal.

8.4.1 Terminology in metallurgy

Minerals: A mineral may be a single compound or a complex mixture of various compounds of metals found in the Earth.

Ore: The mineral from which a metal can be readily and economically extracted on a large scale is said to be an ore.



For example: Clay (Al_2O_3. 2 SiO_2. 2 H_2O) and bauxite (Al_2O_3.2 H_2O) are the two minerals of aluminium, but aluminium can be profitably extracted only from bauxite. Hence, bauxite is an ore of aluminium and clay is its mineral.

Mining: The process of extracting the ores from the Earth's crust is called mining.

Gangue or Matrix: The rocky impurity associated with an ore is called gangue or matrix.

Flux: It is the substance added to the ore to reduce the fusion temperature and to remove the impurities. E.g. Calcium oxide (basic), Silica (acidic). If the gangue is acidic, then basic flux is added and vice versa.

Slag: It is the fusible product formed when a flux reacts with a gangue during the extraction of metals.

$$\text{Flux} + \text{Gangue} \rightarrow \text{Slag}$$

Smelting: Smelting is the process of reducing the roasted metallic oxide from the metal in its molten condition. In this process, impurities are removed as slag by the addition of flux.

8.4.2 Types of separation or concentration of an ore

There are four major types of separation of ores based on the nature of the ore. The different kinds of ores of metals are given in Table 8.1

Concentration of the crushed ore is done mainly by the following methods: -

(i) **Hydraulic (Gravity Separation) method**

Principle: The difference in the densities or specific gravities of the ore and the gangue is the main principle behind this method. Oxide ores are purified by this method. e.g., Haematite Fe_2O_3 the ore of iron.

Method: The ore is poured over a sloping, vibrating corrugated table with grooves and a jet of water is allowed to flow over it. The denser ore particles settle down in the grooves and lighter gangue particles are washed down by water.

(ii) **Magnetic separation method**

Principle: The magnetic properties of the ores form the basis of separation. When either the ore or the gangue is magnetic, this method is employed. e.g., Tinstone SnO_2, the ore of tin.

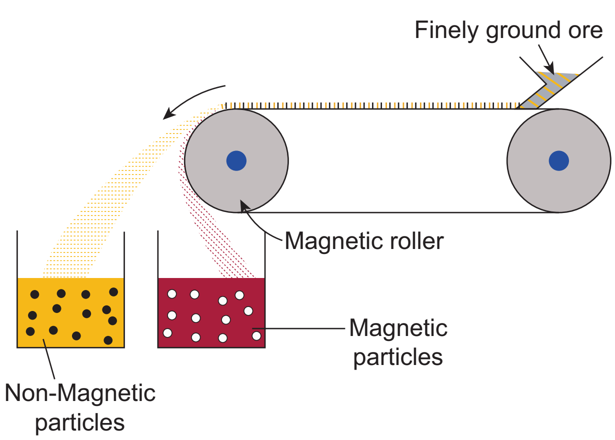


Figure 8.8 Magnetic separation

Method: The crushed ore is placed over a conveyer belt which rotates around two metal wheels, one of which is magnetic. The magnetic particles are attracted to the magnetic wheel and fall separately apart from the non-magnetic particles.

(iii) **Froth floatation**

Principle: This process depends on the preferential wettability of the ore with oil (pine oil) and the gangue particles by water. Lighter ores, such as sulphide ores, are concentrated by this method. e.g., Zinc blende (ZnS).

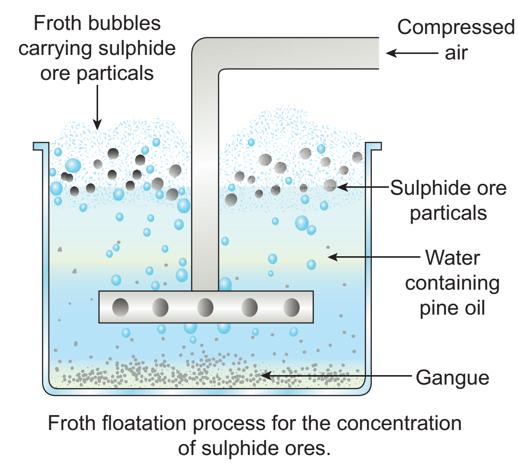


Figure 8.9 Froth floatation

Method: The crushed ore is taken in a large tank containing oil and water and agitated with a current of compressed air.The ore is wetted by the oil and gets separated from the gangue in the form of froth. Since the ore is lighter, it comes on the surface with the froth and the impurities are left behind. e.g., Zinc blende (ZnS).

(iv) **Chemical method or Leaching**

This method is employed when the ore is in a very pure form.

Table 8.1 Types of ores

Oxide Ores	Carbonate Ores	Halide Ores	Sulphide Ores
Bauxite ($Al_2O_3{\cdot}2H_2O$)	Marble ($CaCO_3$)	Cryolite(Na_3AlF_6)	Galena (PbS)
Cuprite(Cu_2O)	Magnesite (($MgCO_3$)	Fluorspar(CaF_2)	Iron pyrite (FeS_2)
Haematite (Fe_2O_3)	Siderite($FeCO_3$)	Rock salt (NaCl)	Zinc blende (ZnS)

More to Know

Extraction of metal from metal oxide can be categorized into three types.

More reactive metals	Medium reactive metals	Less reactive metals
Na,K,Ca,Mg,Al	Zn,Fe,Pb,Cu	Ag,Hg
Electrolytic reduction of metal oxide into metal	Chemical reduction of metal oxide into metal using coke	Thermal decomposition of metal oxide into metal

The ore is treated with a suitable reagent such that the ore is soluble in it but the impurities are not. The impurities are removed by filtration. The solution of the ore, ie., the filtrate is treated with a suitable reagent which precipitates the ore. E.g. Bauxite $Al_2O_3.2H_2O$, the ore of aluminium.

8.5 OCCURRENCE OF ORES IN TAMIL NADU

Lime stone: Coimbatore, Cuddalore, Dindugul

Gypsum: Tiruchi and Coimbatore Distiricts

Titanium minerals: Kanyakumari, Tirunelveli and Tuticorin.

Chromite: Coimbatore and Salem district.

Magnetite:.Dharmapuri, Erode, Salem, Thiruvannamalai.

Tungsten: Madurai and Dindugal.

(Reference: mineral resources of Tamil Nadu-ENVIS Centre, Tamil Nadu)

8.6 PROPERTIES OF METALS

8.6.1 Physical properties

1. **Physical state:** All metals are solids at room temperature except mercury and gallium.
2. **Lustre:** Metals possess a high lustre (called metallic lustre).
3. **Hardness:** Most of the metals are hard and strong (exceptions: sodium and potassium can be cut with a knife)
4. **Melting point and Boiling point:** Usually, metals possess high melting and boiling points and vaporize only at high temperatures (exceptions: gallium, mercury, sodium and potassium).
5. **Density:** Metals have a high density (exceptions: sodium and potassium are less dense than water).
6. **Ductility:** Metals are usually ductile. In other words, they can be drawn into thin wires without breaking.
7. **Malleability:** Metals are usually malleable, i.e, they can be beaten into thin sheets without cracking (except zinc and mercury).
8. **Conduction of heat and electricity:** Metals are good conductors of heat and electricity; silver and copper excel in this property (exception: tungsten)
9. **Solubility:** Usually, metals do not dissolve in liquid solvents.

8.6.2 Chemical Properties

- **Valence electrons:** Atoms of metals usually have 1,2 or 3 electrons in their outermost shell.
- **Formation of ions:** Metals form Positive ions by the loss of electrons and hence they are electro positive.
- **Discharge of ions:** Metals are discharged at the cathode during the electrolysis of their compounds.
- **Atomicity:** Molecules of metals in their vapour state are usually monoatomic.
- **Nature of oxides:** Oxides of metals are usually basic.

8.7 EXTRACTIVE METALLURGY OF ALUMINIUM

Aluminium is the metal found most abundantly in the Earth's crust. Since it is a reactive metal, it occurs in the combined state. The important ores of aluminium are as follows

Ores of Aluminium	Formula
Bauxite	$Al_2O_3{\cdot}2H_2O$
Cryolite	Na_3AlF_6
Corundum	Al_2O_3

Bauxite is the chief ore of aluminium. The extraction of aluminium from bauxite involves two steps:

(i) Conversion of bauxite into alumina – Baeyer's Process

The conversion of Bauxite into Alumina involves the following steps:

Bauxite ore is finely ground and heated under pressure with a solution of concentrated caustic soda solution at 150° C to obtain sodium meta aluminate.

On diluting sodium meta aluminate with water, a precipitate of aluminium hydroxide is formed.

The precipitate is filtered, washed, dried and ignited at 1000°C to get alumina.

$$2Al(OH)_3 \xrightarrow{1000^\circ c} Al_2O_3 + 3H_2O$$

(ii) Electrolytic reduction of alumina – Hall's Process

Aluminium is produced by the electrolytic reduction of fused alumina (Al_2O_3) in the electrolytic cell.

Cathode: Iron tank linked with graphite

Anode: A bunch of graphite rods suspended in molten electrolyte.

Electrolyte: Pure alumina+ molten cryolite + fluorspar (fluorspar lowers the fusion temperature of electrolyte)

Temperature: 900 - 950 °C

Voltage used: 5-6 V

Overall reaction: $2\ Al_2O_3 \rightarrow 4\ Al + 3\ O_2\uparrow$

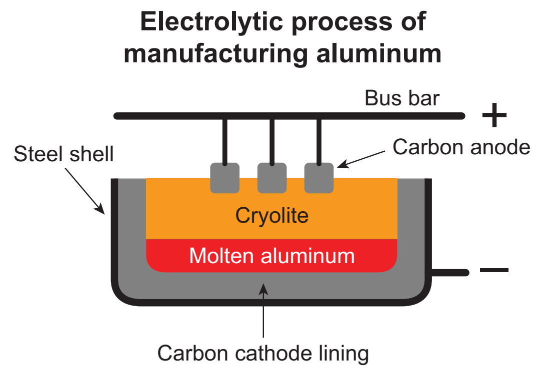


Figure 8.10 Hall's Process

Aluminium is deposited at the cathode and oxygen gas is liberated at the anode. Oxygen combines with graphite to form CO_2.

Physical Properties of Aluminium

- It is a silvery white metal
- It has low density (2.7) and it is light
- It is malleable and ductile
- It is a good conductor of heat and electricity.
- Its melting point is 660 °C.
- It can be polished to produce a shiny attractive appearance.

Chemical Properties of Aluminium

i. **Reaction with air:** It is not affected by dry air. On heating at 800 °C, aluminium burns very brightly forming it's oxide and nitride.

$$4\ Al + 3\ O_2 \rightarrow 2\ Al_2O_3 \text{(Aluminium oxide)}$$

$$2\ Al + N_2 \rightarrow 2\ AlN \text{ (Aluminium nitride)}$$

ii. **Reaction with water:** Water does not react with aluminium due to the layer of oxide on it. When steam is passed over red hot aluminium, hydrogen is produced.

$$2\ Al + \underset{\text{(steam)}}{3\ H_2O} \rightarrow \underset{\text{(aluminium oxide)}}{Al_2O_3} + 3\ H_2\uparrow$$

iii. Reaction with alkalis: It reacts with strong caustic alkalis forming aluminates.

$$2\,Al + 2\,NaOH + 2\,H_2O \rightarrow 2\,NaAlO_2 + 3\,H_2\uparrow$$

(Sodium meta aluminate)

iv. Reaction with acids: With dilute and con. HCl it liberates H_2 gas.

$$2\,Al + 6\,HCl \rightarrow 2\,AlCl_3 + 3\,H_2\uparrow$$

(Aluminium chloride)

Aluminium liberates hydrogen on reaction with dilute sulphuric acid. Sulphur dioxide is liberated with hot concentrated sulphuric acid

$$2\,Al + 3\,H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3\,H_2$$

$$2\,Al + 6\,H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6\,H_2O + 3\,SO_2\uparrow$$

More to Know

Dilute or concentrated nitric acid does not attack aluminium, but it renders aluminium passive due to the formation of an oxide film on its surface.

v. As reducing agent: Aluminium is a powerful reducing agent. When a mixture of aluminium powder and iron oxide is ignited, the latter is reduced to metal. This process is known as **aluminothermic process**.

$$Fe_2O_3 + 2\,Al \rightarrow 2\,Fe + Al_2O_3 + \text{Heat}$$

Uses

Aluminium is used in

- household utensils
- electrical cable industry
- making aeroplanes and other industrial mechine parts

8.8 EXTRACTIVE METALLURGY OF COPPER

Occurrence:

It was named as cuprum by the Romans because they got it from the Island of Cyprus. Copper is found in the native state as well as combined state.

Ores of copper	**Formula**
Copper pyrites	$CuFeS_2$
Cuprite or ruby copper	Cu_2O
Copper glance	Cu_2S

The chief ore of copper is copper pyrite. It yields nearly 76% of the world production of copper. Extraction of copper from copper pyrites involves the following steps

i. Concentration of ore: The ore is crushed and the concentrated by froth floatation process.

ii. Roasting: The concentrated ore is roasted in excess of air. During the process of roasting, the moisture and volatile impurities are removed. Sulphur, phosphorus, arsenic and antimony are removed as oxides. Copper pyrite is partly converted into sulphides of copper and iron.

$$2\,CuFeS_2 + O_2 \longrightarrow Cu_2S + 2\,FeS + SO_2\uparrow$$

iii. Smelting: The roasted ore is mixed with powdered coke and sand and is heated in a blast furnace to obtain matte (Cu_2S + FeS) and slag. The slag is removed as waste.

iv. Bessemerisation: The molten matte is transferred to Bessemer converter in order to obtain blister copper. Ferrous sulphide from matte is oxidized to ferrous oxide, which is removed as slag using silica.

$$2\,FeS + 3\,O_2 \longrightarrow 2\,FeO + 2\,SO_2\uparrow$$

$$FeO + SiO_2 \longrightarrow FeSiO_3\ \text{(slag)}$$

(Iron silicate)

$$2\,Cu_2S + 3O_2 \longrightarrow 2\,Cu_2O + 2\,SO_2\uparrow$$

$$2\,Cu_2O + Cu_2S \longrightarrow 6\,Cu + SO_2\uparrow$$

(Blister copper)

v. Refining: Blister copper contains 98% of pure copper and 2% of impurities and is purified by **electrolytic refining**. This method is used to get metal of a high degree of purity. For electrolytic refining of copper, we use:

Cathode: A thin plate of pure copper metal.

Anode: A block of impure copper metal.

Electrolyte: Copper sulphate solution acidified with sulphuric acid.

When electric current is passed through the electrolytic solution, pure copper gets deposited at the cathode and the impurities settle at the bottom of the anode in the form of sludge called anode mud.

Physical Properties of Copper

Copper is a reddish brown metal, with high lustre, high density and high melting point (1356°C).

Chemical Properties of Copper

i. **Action of Air and Moisture:** Copper gets covered with a green layer of basic copper carbonate in the presence of CO_2 and moisture.

$$2\,Cu + O_2 + CO_2 + H_2O \rightarrow CuCO_3.Cu(OH)_2$$

ii. **Action of Heat**: On heating at different temperatures in the presence of oxygen, copper forms two types of oxides CuO, Cu_2O.

$$2\,Cu + O_2 \xrightarrow{\text{below 1370K}} 2\,CuO$$

(copper II oxide- black)

$$4\,Cu + O_2 \xrightarrow{\text{above 1370K}} 2\,Cu_2O$$

(copper I oxide – red)

iii. Action of Acids:

a) With dilute HCl and dilute H_2SO_4:

Dilute acids such as HCl and H_2SO_4 have no action on these metals in the absence of air. Copper dissolves in these acids in the presence of air.

$$2\,Cu + 4\,HCl + O_2\,(air) \longrightarrow 2\,CuCl_2 + 2\,H_2O$$

b) With dil. HNO_3:

Copper reacts with dil. HNO_3 with the liberation of Nitric Oxide gas.

$$3\,Cu + 8\,HNO_3 \rightarrow Cu(NO_3)_2 + 2\ NO \uparrow + 2H_2O$$

$$Cu + 2\,H_2SO_4 \rightarrow CuSO_4 + SO_2 \uparrow + 2\,H_2O$$

iv) Action of Chlorine:

Chlorine reacts with copper, resulting in the formation of copper(II) chloride.

$$Cu + Cl_2 \longrightarrow CuCl_2$$

v) Action of Alkalis:

Copper is not attacked by alkalis.

Uses of Copper:

i. It is extensively used in manufacturing electric cables and other electric appliances.
ii. It is used for making utensils, containers, calorimeters and coins,
iii. It is used in electroplating.
iv. It is alloyed with gold and silver for making coins and jewels

8.9 EXTRACTIVE METALLURGY OF IRON

Occurrence:

Iron is the second most abundant metal available next to aluminium. It occurs in nature as oxides, sulphides and carbonates. The ores of iron are as follows:

Ores of iron	Formula
Haematite	Fe_2O_3
Magnetite	Fe_3O_4
Iron pyrite	FeS_2

Iron is chiefly extracted from haematite ore (Fe_2O_3)

i. **Concentration by Gravity Separation:** The powdered ore is washed with a steam of water. As a result, the lighter sand particles and other impurities are washed away and the heavier ore particles settle down.

ii. **Roasting and Calcination:** The concentrated ore is strongly heated in a limited supply of air in a reverberatory furnace. As a result, moisture is driven out and sulphur, arsenic and phosphorus impurities are oxidized off.

iii. Smelting (in a Blast Furnace): The charge consisting of roasted ore, coke and limestone in the ratio 8:4:1 is smelted in a blast furnace by introducing it through the cup and cone arrangement at the top. There are three important regions in the furnace.

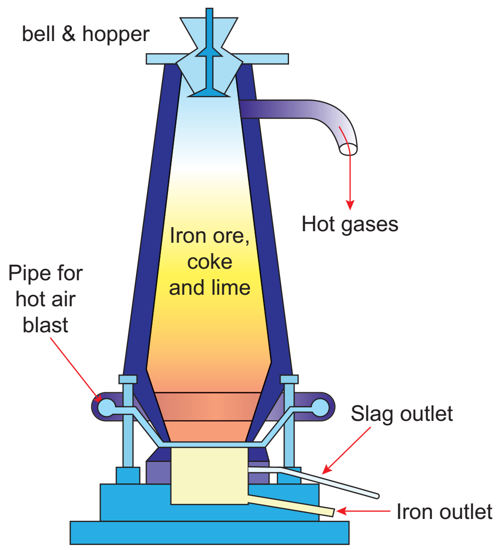


Figure 8.11 Blast Furnace

(a) The Lower Region (Combustion Zone)- The temperature is at 1500°C. In this region, coke burns with oxygen to form CO_2 when the charge comes in contact with a hot blast of air.

$$C + O_2 \xrightarrow[\Delta]{1500°C} CO_2 + \text{Heat}$$

It is an exothermic reaction since heat is liberated.

(b) The Middle Region (Fusion Zone) – The temperature prevails at 1000°C. In this region, CO_2 is reduced to CO.

$$CO_2 + C \xrightarrow[\Delta]{1000°C} 2\,CO - \text{Heat}$$

Limestone decomposes to calcium oxide and CO_2.

$$CaCO_3 \xrightarrow[\Delta]{} CO_2 - \text{Heat}$$

These two reactions are endothermic due to absorption of heat. Calcium oxide combines with silica to form calcium silicate slag.

$$CaO + SiO_2 \longrightarrow CaSiO_3$$

(c) The Upper Region (Reduction Zone)- The temperature prevails at 400°C . In this region carbon monoxide reduces ferric oxide to form a fairly pure spongy iron.

$$Fe_2O_3 + 3CO \xrightarrow{400°C} 2Fe + 3CO_2$$

The molten iron is collected at the bottom of the furnace after removing the slag.

The iron thus formed is called pig iron. It is remelted and cast into different moulds. This iron is called cast iron.

Physical properties:

i. It is a lustrous metal, greyish white in colour.

ii. It has high tensility, malleability and ductility.

iii. It can be magnetized.

Chemical properties:

i. **Reaction with air or oxygen:** Only on heating in air, iron forms magnetic oxide.

$$3\,Fe + 2\,O_2 \longrightarrow Fe_3O_4 \text{ (black)}$$

ii. **Reaction with moist air:** When iron is exposed to moist air, it forms a layer of brown hydrated ferric oxide on its surface. This compound is known as rust and the phenomenon of formation of rust is known as **rusting**.

$$4\,Fe + 3\,O_2 + x\,H_2O \longrightarrow 2\,Fe_2O_3 \cdot xH_2O \text{(rust)}$$

iii. **Reaction with steam:** When steam is passed over red hot iron, magnetic oxide is formed.

$$3\,Fe + 4\,H_2O \text{ (steam)} \longrightarrow Fe_3O_4 + 4\,H_2 \uparrow$$

iv. **Reaction with chlorine:** Iron combines with chlorine to form ferric chloride.

$$2Fe + 3Cl_2 \longrightarrow 2FeCl_3 \text{ (ferric chloride)}$$

v. **Reaction with acids:** With dilute HCl and dilute H_2SO_4 it liberates H_2 gas.

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

$$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2 \uparrow$$

With dilute HNO_3 in cold condition it gives ferrous nitrate.

$$4\,Fe + 10\,HNO_3 \rightarrow 4\,Fe(NO_3)_2 + NH_4NO_3 + 3\,H_2O$$

With con. H_2SO_4 it forms ferric sulphate.

$$2\ Fe + 6\ H_2SO_4 \rightarrow Fe_2(SO_4)_3 + 3\ SO_2 + 6\ H_2O$$

When iron is dipped in con. HNO_3 it becomes chemically passive or inert due to the formation of a layer of iron oxide (Fe_3O_4) on its surface.

Uses of iron

Pig iron (Iron with 2-4.5% of carbon)**:** It is used in making pipes, stoves, radiators, railings, manhole covers and drain pipes.

Steel (Iron with < 0.25% of carbon)**:** It is used in the construction of buildings, machinery, transmission cables and T.V towers and in making alloys.

Wrought iron (Iron with 0.25-2% of wraught carbon)**:** It is used in making springs, anchors and electromagnets.

8.10 ALLOYS

An alloy is a homogeneous mixture of two or more metals or of one or more metals with certain non-metallic elements.

The properties of alloys are often different from those of its components. Pure gold is too soft to be used. The addition of small percentage of copper enhances its strength and utility.

8.10.1 Amalgam

An amalgam is an alloy of mercury with another metal. These alloys are formed through metallic bonding with the electrostatic force of attraction between the electrons and the positively charged metal ions. Silver tin amalgam is used for dental filling.

Reasons for alloying:

i. To modify appearance and colour
ii. To modify chemical activity.
iii. To lower the melting point.
iv. To increase hardness and tensile strength.
v. To increase resistance to electricity.

8.10.2 Method of making alloys

(a) By fusing the metals together. E.g. Brass is made by melting zinc and copper.

(b) By compressing finely divided metals. E.g. Wood metal: an alloy of lead, tin, bismuth and cadmium powder is a fusible alloy.

Alloys as solid solutions:

Alloys can be considered solid solutions in which the metal with high concentration is solvent and other metals are solute.

For example, brass is a solid solution of zinc (solute) in copper (solvent).

8.10.3 Types of Alloys

Based on the presence or absence of Iron, alloys can be classified into:

- Ferrous alloys: Contain Iron as a major component. A few examples of ferrous alloys are Stainless Steel, Nickel Steel etc.
- Non-ferrous alloys: These alloys do not contain Iron as a major component. For example, Aluminium alloy, Copper alloy etc.

Copper Alloys (Non- ferrous)

Alloys	Uses
Brass (Cu, Zn)	Electrical fittings, medal, decorative items, hardware
Bronze (Cu, Sn)	Statues, coins, bells, gongs

Aluminium Alloys (Non- ferrous)

Alloys	Uses
Duralumin (Al, Mg, Mn, Cu)	Aircrafts, tools, pressure cookers
Magnalium (Al, Mg)	Aircraft, scientific instruments

Iron Alloys(Ferrous)

Alloys	Uses
Stainless steel (Fe,C, Ni,Cr)	Utensils, cutlery, automobile parts
Nickel steel (Fe,C,Ni)	Cables , aircraftparts, propeller

8.11 CORROSION

It is the gradual destruction of metals by chemical or electrochemical reaction with the environment. It is a natural process which converts a metal into its oxide, hydroxide or sulphide so that it loses its metallic characteristics.

Rusting

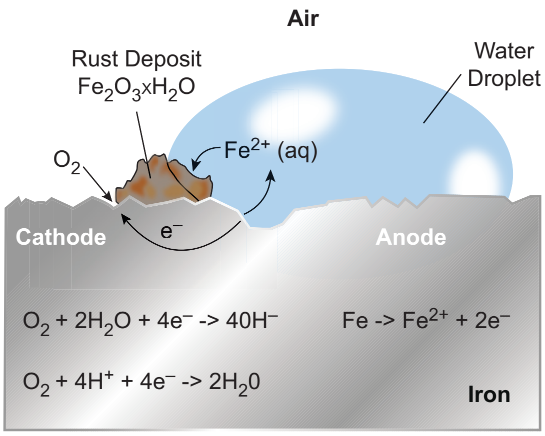


Figure 8.12 Rusting

Rust is chemically known as hydrated ferric oxide (it is formulated as $Fe_2O_3{\cdot}xH_2O$). Rusting results in the formation of scaling reddish brown hydrated ferric oxide on the surface of iron and iron containing materials.

8.11.1 Types of Corrosion

i. **Dry Corrosion or Chemical Corrosion:** The corrosive action in the absence of moisture is called dry corrosion. It is the process of a chemical attack on a metal by a corrosive liquids or gases such as O_2, N_2, SO_2, H_2S etc. It occurs at high temperature. Of all the gases mentioned above O_2 is the most reactive gas to impart the chemical attack.

ii. **Wet Corrosion or Electrochemical Corrosion:** The corrosive action in the presence of moisture is called wet corrosion. It occurs as a result of electrochemical reaction of metal with water or aqueous solution of salt or acids or bases.

8.11.2 Methods of preventing corrosion

i. **Alloying:** The metals can be alloyed to prevent the process of corrosion. E.g: Stainless Steel

ii. **Surface Coating:** It involves application of a protective coating over the metal. It is of the following types:

a) **Galvanization:** It is the process of coating zinc on iron sheets by using electric current.

b) **Electroplating:** It is a method of coating one metal over another metal by passing electric current.

c) **Anodizing:** It is an electrochemical process that converts the metal surface into a decorative, durable and corrosion resistant. Aluminium is widely used for anodizing process.

d) **Cathodic Protection:** It is the method of controlling corrosion of a metal surface protected is coated with the metal which is easily corrodible. The easily corrodible metal is called Sacrificial metal to act as anode ensuring cathodic protection.

8.12 PAMBAN BRIDGE

It is a railway bridge which connects the town of Rameshwaram on Pamban Island to mainland India. Opened on 1914, it was India's first sea bridge in India until the opening of the BandraWorli Sea Link in 2010. We can control the corrosion and renovation of historical pamban bridge by a periodical protective coating which will be the strong example for applied chemistry to uphold our history.

Figure 8.12 Pamban Bridge

Points to Remember

- Modern periodic law states that, the physical and chemical properties of the elements are the periodic functions of their atomic numbers.
- The table in which elements are arranged in rows and columns in regular gradation is called periodic table.
- Smelting is the process of reducing the roasted metallic oxide into metal in molten condition.
- Dilute or con. HNO_3 does not attack aluminium metal ,as it renders aluminium passive due to oxide film formation on its surface.
- The charge used in the metallurgy of iron consists of roasted ore, coke and limestone in the ratio, 8:4:1.
- Copper vessel on exposure to air and moisture forms a green layer on its surface due to basic copper carbonate.
- An alloy is a homogeneous mixture of two or more metals.
- An amalgam is an alloy of mercury with another metal. E.g. Ag-Sn amalgam is used for dental filling.
- The chemical name of rust is hydrated ferric oxide and its formula is $Fe_2O_3{\cdot}xH_2O$.

FBKZ2Y

TEXTBOOK EVALUATION

I. Choose the best answer.

1. The number of periods and groups in the periodic table are______.
   a) 6,16 b) 7,17
   c) 8,18 d) 7,18

2. The basis of modern periodic law is______.
   a) atomic number
   b) atomic mass
   c) isotopic mass
   d) number of neutrons

3. _____ group contains the member of halogen family.
   a) 17^{th} b) 15^{th}
   c) 18^{th} d) 16^{th}

4. _____ is a relative periodic property
   a) atomic radii b) ionic radii
   c) electron affinity d) electronegativity

5. Chemical formula of rust is _________.
   a) $FeO.xH_2O$ b) $FeO_4.xH_2O$
   c) $Fe_2O_3.xH_2O$ d) FeO

6. In the alumino thermic process the role of Al is _____.
   a) oxidizing agent
   b) reducing agent
   c) hydrogenating agent
   d) sulphurising agent

7. The process of coating the surface of metal with a thin layer of zinc is called______.
   a) painting b) thinning
   c) galvanization d) electroplating

8. Which of the following have inert gases 2 electrons in the outermost shell.
   a) He b) Ne
   c) Ar d) Kr

9. Neon shows zero electron affinity due to _____.
   a) stable arrangement of neutrons
   b) stable configuration of electrons
   c) reduced size
   d) increased density

10. ______ is an important metal to form amalgam.

a) Ag b) Hg
c) Mg d) Al

II. Fill in the blanks

1. If the electronegativity difference between two bonded atoms in a molecule is greater than 1.7, the nature of bonding is ______
2. ________ is the longest period in the periodical table.
3. ________ forms the basis of modern periodic table.
4. If the distance between two Cl atoms in Cl_2 molecule is 1.98Å, then the radius of Cl atom is ________.
5. Among the given species A^-,A^+, and A, the smallest one in size is ________.
6. The scientist who propounded the modern periodic law is ________.
7. Across the period, ionic radii ________ (increases,decreases).
8. ________ and ________ are called inner transition elements.
9. The chief ore of Aluminium is ________.
10. The chemical name of rust is ________.

III. Match the following

1. Galvanisation	:	Noble gas elements
2. Calcination	:	Coating with Zn
3. Redox reaction	:	Silver-tin amalgam
4. Dental filling	:	Alumino thermic process
5. Group 18 elements	:	Heating in the absence of air

IV. True or False: (If false give the correct statement)

1. Moseley's periodic table is based on atomic mass.
2. Ionic radius increases across the period from left to right.
3. All ores are minerals; but all minerals cannot be called as ores;
4. Al wires are used as electric cables due to their silvery white colour.
5. An alloy is a heterogenous mixture of metals.

V. Assertion and Reason

Answer the following questions using the data given below:

i) A and R are correct, R explains the A.
ii) A is correct, R is wrong.
iii) A is wrong, R is correct.
iv) A and R are correct, R doesn't explains A.

1. **Assertion** : The nature of bond in HF molecule is ionic
   Reason : The electronegativity difference between H and F is 1.9
2. **Assertion :** Magnesium is used to protect steel from rusting
   Reason : Magnesium is more reactive than iron
3. **Assertion :** An uncleaned copper vessel is covered with greenish layer.
   Reason : copper is not attacked by alkali

VI. Short answer questions

1. A is a reddish brown metal, which combines with O_2 at < 1370 K gives B, a black coloured compound. At a temperature > 1370 K, A gives C which is red in colour. Find A,B and C with reaction.
2. A is a silvery white metal. A combines with O_2 to form B at 800°C, the alloy of A is used in making the aircraft. Find A and B
3. What is rust? Give the equation for formation of rust.
4. State two conditions necessary for rusting of iron.

VII. Long answer questions

1. a) State the reason for addition of caustic alkali to bauxite ore during purification of bauxite.

   b) Along with cryolite and alumina, another substance is added to the electrolyte mixture. Name the substance and give one reason for the addition.

2. The electronic configuration of metal A is 2,8,18,1.

   The metal A when exposed to air and moisture forms B a green layered compound. A with con. H_2SO_4 forms C and D along with water. D is a gaseous compound. Find A,B,C and D.

3. Explain smelting process.

VIII. HOT questions

1. Metal A belongs to period 3 and group 13. A in red hot condition reacts with steam to form B. A with strong alkali forms C. Find A,B and C with reactions

2. Name the acid that renders aluminium passive. Why?

3. a) Identify the bond between H and F in HF molecule.

   b) What property forms the basis of identification?

   c) How does the property vary in periods and in groups?

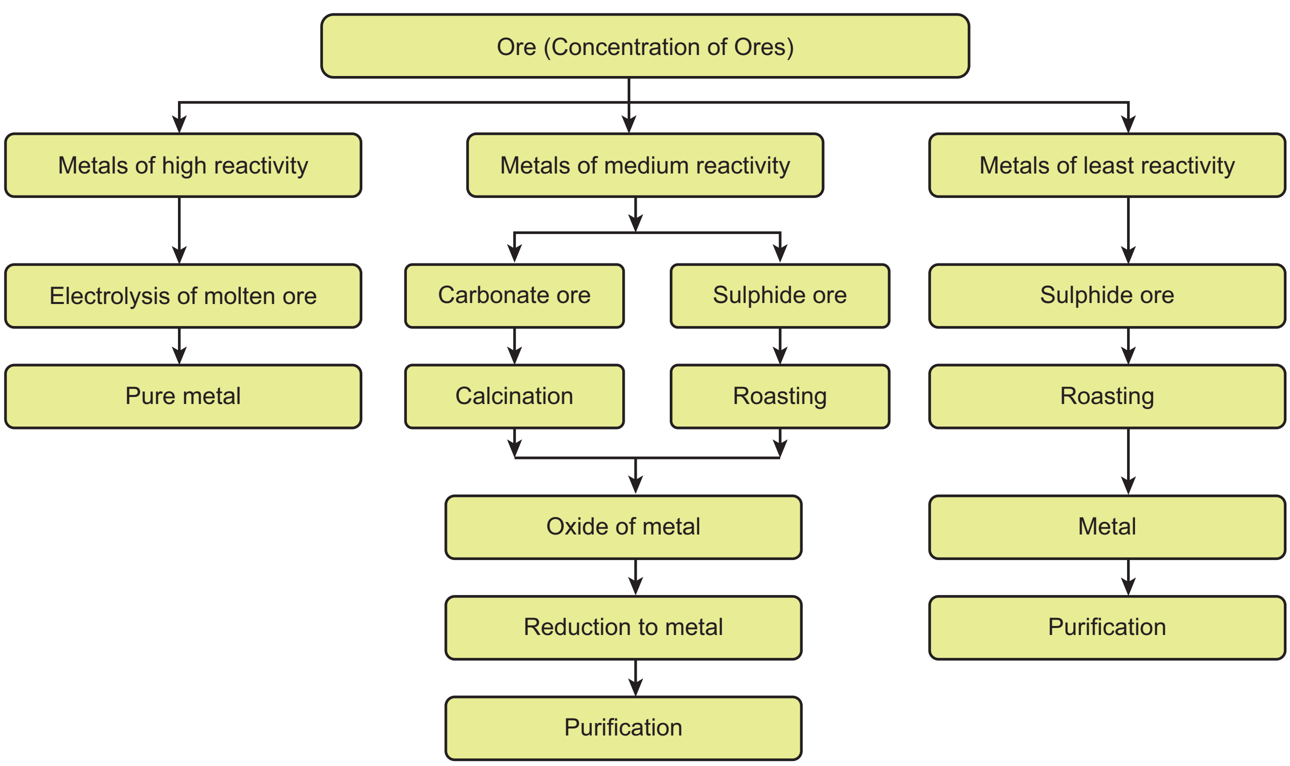
REFERENCE BOOKS

1. Inorganic chemistry by PL Soni
2. Physical chemistry by Puri and Sharma
3. Inorganic chemistry by Atkins
4. Oxford Inorganic chemistry

INTERNET RESOURCES

- https://www.webelements.com
- www.rsc.orgperiodic-table
- https://www.tcyonline.com

CONCEPT MAP



UNIT 9

SOLUTIONS

FQUY2M

Learning Objectives

After studying this lesson, students will able to

- define solution.
- recognize the types of solutions.
- analyse the factors influencing solubility.
- explain the various modes of expression of concentration of solution.
- calculate the solubility of solutes in solvents.
- correlate the hydrated salts and anhydrous salts.
- distinguish between deliquescent and hygroscopic substances.

INTRODUCTION

You have learnt about mixtures in your lower classes. Most of the substances that we encounter in our daily life are mixtures of two or more substances. The substances present in a mixture may exist in one or more physical state. For example, when we burn wood, the smoke released is a mixture of solid carbon and gases like CO_2, CO, etc.

In some cases of mixtures, their components can be separated easily whereas in some other cases they cannot be. Consider the two mixtures, one which contains salt and water, and the another which contains sand and water. Water is the one of the components in both the mixtures. In the first case salt disolves in water. In the second case the sand does not disolve in water. Sand in water can be separated by filtration but salt cannot be separated as it dissolves in water to form a homogeneous mixture. This kind of homogenous mixtures are termed as "**solutions**".

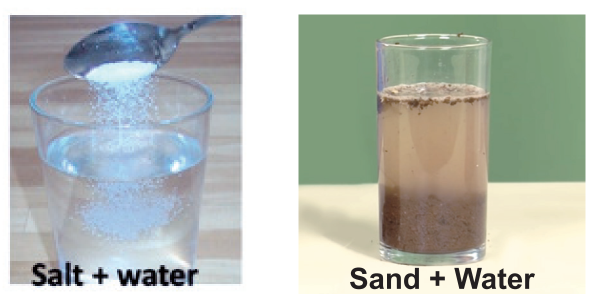


Figure 9.1 Homogeneous and heterogeneous mixtures

9.1 SOLUTIONS IN DAY-TO-DAY LIFE

One of the naturally existing solutions is sea water. We cannot imagine life on earth without sea water. It is a mixture of many dissolved salts. The another one is air. It is a mixture of gases like nitrogen, oxygen, carbon dioxide and other gases.

All the life forms on the earth are associated with solutions. Plants take solutions of nutrients for their growth from the soil. Most of the liquids found in human body including blood, lymph and urine are solutions. Day to day human activities like washing, cooking, cleaning and few other activities involve the formation of solutions with water. Similarly, the drinks what we take, like fruit juice, aerated drinks, tea, coffee etc. are also solutions. Therefore, the ability of water to form solutions is responsible for sustenance of life. On the other hand, the same characteristic forms the basic cause of the addition of pollutants to water. However, the ability of water to form solutions influences the survival of man on the earth. In this lesson, let us learn the science of solutions.

9.2 COMPONENTS OF SOLUTIONS

We know that, a **solution is a homogeneous mixture of two or more substances**. In a solution, the component which is present in lesser amount (by weight), is called **solute** and the component, which is present in a larger amount (by weight) is called **solvent**. The solute gets distributed uniformly throughout the solvent and thus forming the mixture homogeneous. So, the solvent acts as a dissolving medium in a solution. The process of uniform distribution of solute into solvent is called **dissolution**. Figure 9.2 shows the schematic representation of solution.

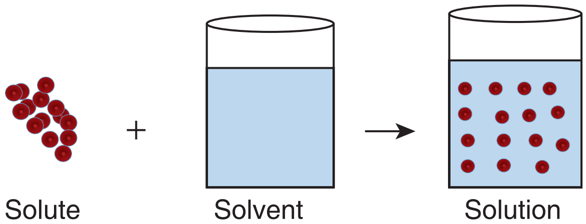
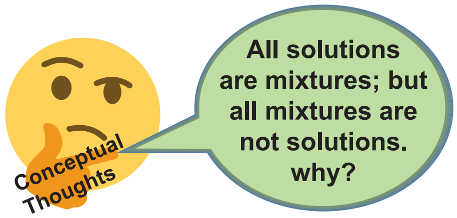


Figure 9.2 Formation of solution



A solution must at least be consisting of two components (a solute and a solvent). Such solutions which are made of one solute and one solvent (two components) are called **binary solutions**. e.g. On adding copper sulphate crystals to water, it dissolves in water forming a solution of copper sulphate as shown in Figure 9.3. It contains two components i.e. one solute- copper sulphate and one solvent-water. So it is a binary solution. Similarly, a solution may contain more than two components. For example if salt and sugar are added to water, both dissolve in water forming a solution. Here two solutes are dissolved in one solvent. Such kind of solutions which contain three components are called **ternary solutions**.

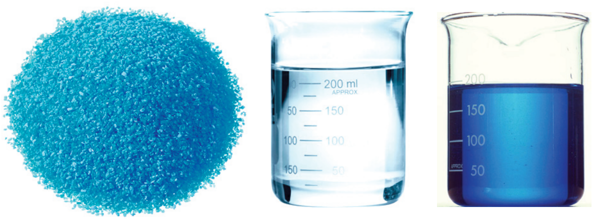


Figure 9.3 Formation of Copper sulphate solution

9.3 Types of Solutions

9.3.1 Based on the physical state of the solute and the solvent

We know that substances normally exist in three physical states (phases) i.e., solid, liquid and gas. In binary solutions, both the solvent and solute may exist in any of these physical states. But the solvent constitutes the major part of the solution. Its physical state is the primary factor which determine the characteristics of the solution. Therefore, there are different types of binary solutions as listed in Table 9.1.

Table 9.1 Types of binary solutions

Solute	Solvent	Example
Solid solution		
Solid	Solid	Copper dissolved in gold (Alloys)
Liquid	Solid	Mercury with sodium (amalgam)
Liquid solution		
Solid	Liquid	Sodium chloride dissolved in water
Liquid	Liquid	Ethyl alcohol dissolved in water
Gas	Liquid	carbon-di-oxide dissolved in water (Soda water)
Gaseous solution		
Liquid	Gas	Water vapour in air (cloud)
Gas	Gas	Mixture of Helium-Oxygen gases,

9.3.2 Based on the type of solvent

Most of the substances are soluble in water. That is why, water is called as 'Universal solvent'. However some substances do not dissolve in water. Therefore, other solvents such as ethers, benzene, alcohols etc., are used to prepare a solution. On the basis of type of solvent, solutions are classified into two types. They are aqueous solutions and non-aqueous solutions.

a) Aqueous solution:

The solution in which water acts as a solvent is called aqueous solution. In general, ionic compounds are soluble in water and form aqueous solutions more readily than covalent compounds. E.g. Common salt in water, Sugar in water, Copper sulphate in water etc.

b) Non – Aqueous solution:

The solution in which any liquid, other than water, acts as a solvent is called non-aqueous solution. Solvent other than water is referred to as non-aqueous solvent. Generally, alcohols, benzene, ethers, carbon disulphide, acetone, etc., are used as non-aqueous solvents. Examples for non-aqueous solutions: Sulphur dissolved in carbon disulphide, Iodine dissolved in carbon tetrachloride.

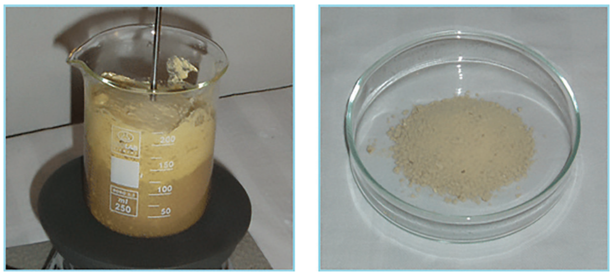


Figure 9.4 Sulphur in carbon-di-sulphide (Soluble), Sulphur in water (Insoluble)

9.3.3 Based on the amount of solute

The amount of the solute that can be dissolved in the given amount of solvent is limited under any given conditions. Based on the amount of solute, in the given amount of solvent, solutions are classified into the following types:

(i) Saturated solution

(ii) Unsaturated solution

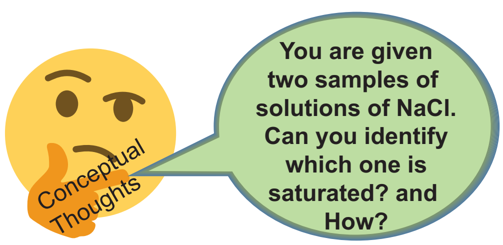
(iii) Super saturated solution

(i) Saturated solution: A solution in which no more solute can be dissolved in a definite amount of the solvent at a given temperature is called saturated solution. e.g. 36 g of sodium chloride in 100 g of water at 25°C forms saturated solution.

Further addition of sodium chloride, leave it undissolved.

(ii) Unsaturated solution: Unsaturated solution is one that contains less solute than that of the saturated solution at a given temperature. e.g. 10 g or 20 g or 30 g of Sodium chloride in 100 g of water at 25°C forms an unsaturated solution.

(iii) Super saturated solution: Supersaturated solution is one that contains more solute than the saturated solution at a given temperature. e.g. 40 g of sodium chloride in 100 g of water at 25°C forms super saturated solution. This state can be achieved by altering any other conditions liken temperature, pressure. Super saturated solutions are unstable, and the solute is reappearing as crystals when the solution is disturbed.



9.3.4 Concentrated and dilute solutions

It is another kind of classification of unsaturated solutions. It expresses the relative concentration of two solutions with respect to their solutes present in the given amount of the solvent. For example, you are given two cups of tea. When you taste them, you feel that one is sweeter than the other. What do you infer from it? The tea which sweet more contains higher amount of sugar than the other. How can you express your observation? You can say that the tea is stronger. But a chemist would say that it is 'concentrated'.

When we compare two having same solute and solvent in a solutions, the one which contains higher amount of solute per the given amount of solvent is said to be '**concentrated solution**' and the another is said to be '**dilute solution**'. They are schematically represented by Figure 9.5.

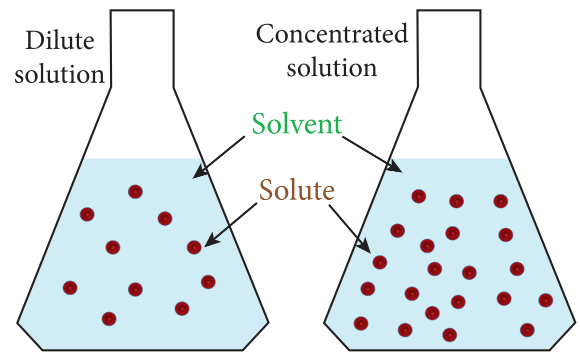


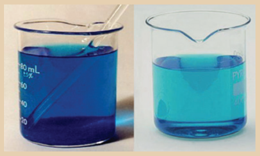
Figure 9.5 Dilute and Concentrated Solution

Differentiating solutions as dilute and concentrated is a qualitative representation. It does not imply the quantity of the solute. This difference is observed by means of some physical characteristics such as colour, density, etc.

Activity 1

Look at the following pictures. Label them as dilute and concentrated solution and justify your answer.

Tea



Copper sulphate

9.4 Solubility

Usually, there is a limit to the amount of solute that can be dissolved in a given amount of solvent at a given temperature. When this limit is reached, we have a saturated solution and any excess solute that is added, simply resides at the bottom of the solution. The extent of dissolution of a solute in a solvent can be better explained by its solubility. Solubility is measure of how much of a solute can be dissolved in a specified amount of a solvent.

Solubility is defined as the number of grams of a solute that can be dissolved in 100 g of a solvent to form its saturated solution at a given temperature and pressure. For example, 36 g of sodium chloride need to be dissolved in 100 g of water to form its saturated solution at 25°C. Thus the solubility of NaCl in water is 36 g at 25°C. The solubility is mathematically expressed as

$$\text{Solubility} = \frac{\text{Mass of the solute}}{\text{Mass of the solvent}} \times 100$$

Table 9.2 Solubility's of some common substances in water at 25°C

Name of the solute	Formula of the solute	Solubility g/100 g water
Calcium carbonate	$CaCO_3(s)$	0.0013
Sodium chloride	NaCl (s)	36
Ammonia	$NH_3(g)$	48
Sodium hydroxide	NaOH(s)	80
Glucose	$C_6H_{12}O_6(s)$	91
Sodium bromide	NaBr(s)	95
Sodium iodide	NaI(s)	184

9.4.1 Factors affecting solubility

There are three main factors which govern the solubility of a solute. They are:

(i) Nature of the solute and solvent

(ii) Temperature

(iii) Pressure

FR4U4A

(i) Nature of the solute and solvent

The nature of the solute and solvent plays an important role in solubility. Although water dissolves an enormous variety of substances, both ionic and covalent, it does not dissolve everything. The phrase that scientists often use when predicting solubility is "like dissolves like." This expression means that dissolving occurs when similarities exist between the solvent and the solute. For example: Common salt is a polar compound and dissolves readily in polar solvent like water.

Non-polar compounds are soluble in non-polar solvents. For example, Fat dissolved in ether. But non-polar compounds, do not dissolve in polar solvents; polar compounds do not dissolve in non-polar solvents.

(ii) Effect of Temperature

Solubility of Solids in Liquid:

Generally, solubility of a solid solute in a liquid solvent increases with increase in temperature. For example, a greater amount of sugar will dissolve in warm water than in cold water.

In endothermic process, solubility increases with increase in temperature.

In exothermic process, solubility decreases with increase in temperature.

Solubility of Gases in liquid

Do you know why is it bubbling when water is boiled? Solubility of gases in liquid decrease with increase in temperature. Generally, water contains dissolved oxygen. When water is boiled, the solubility of oxygen in water decreases, so oxygen escapes in the form of bubbles.

Aquatic animals live more in cold regions because, more amount of dissolved oxygen is present in the water of cold regions. This shows that the solubility of oxygen in water is more at low temperatures.

(iii) Effect of Pressure

Effect of pressure is observed only in the case of solubility of a gas in a liquid. When the pressure is increased, the solubility of a gas in liquid increases.

The common examples for solubility of gases in liquids are carbonated beverages, i.e. soft drinks, household cleaners containing aqueous solution of ammonia, formalin- aqueous solution of formaldehyde, etc.

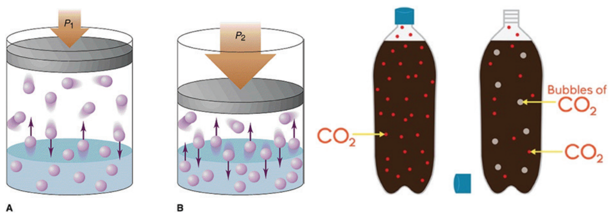


Figure 9.6 Effect of pressure on solubility

More to know

The effect of pressure on the solubility of a gas in liquid is given by **Henry's law**. It states that, the solubility of a gas in a liquid is directly proportional to the pressure of the gas over the solution at a definite temperature.

9.5 Concentration of a Solution

So far, we discussed what is a solution? what does it consist of and its types. Most of the chemical reactions take place in solutions form. So it is essential to quantify the solute in solvent to study the reactions. To quantify the solute in a solution, we can use the term "**concentration**".

Concentration of a solution may be defined as the amount of solute present in a given amount of solution or solvent.

Quantitatively, concentration of a solution may be expressed in different methods. But here, we shall discuss percentage by mass (% mass) and percentage by volume (% volume).

9.5.1 Mass percentage

Mass percentage of a solution is defined as the percentage by mass of the solute present in the solution. It is mostly used when solute is solid and solvent is liquid.

$$\text{Mass Percentage} = \frac{\text{Mass of the sloute}}{\text{Mass of the solution}} \times 100$$

$$\text{Mass Percentage} = \frac{\text{Mass of the sloute}}{\text{Mass of the solute + Mass of the solvent}} \times 100$$

For example: 5% sugar solution (by mass) means 5 g of sugar in 95 g of water. Hence it is made 100g of solution.

Usually, mass percentage is expressed as w/w (weight / weight); mass percentage is independent of temperature.

9.5.2 Volume percentage

Volume percentage is defined as the percentage by volume of solute (in ml) present in the given volume of the solution.

$$\text{Volume Percentage} = \frac{\text{Volume of the solute}}{\text{Volume of the solution}} \times 100$$

$$\text{Volume Percentage} = \frac{\text{Volume of the solute}}{\text{Volume of the solute + volume of the solvent}} \times 100$$

For example, 10% by volume of the solution of ethanol in water, means 10 ml of ethanol in 100 ml of solution (or 90 ml of water)

Usually volume percentage is expressed as v/v (volume / volume). It is used when both the solute and solvent are liquids. Volume percentage decreases with increases in temperature, because of expansion of liquid.

You can notice that in the commercial products that we come across in our daily life such as a solution of syrups, mouth wash, antiseptic solution, household disinfectants etc., the concentration of the ingredients is expressed as v/v. Similarly, in ointments, antacid, soaps, etc., the concentration of solutions are expressed as w/w.

Ointment

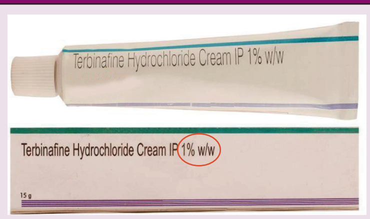


Figure 9.7 Ointment (w/w percent)

9.6 Hydrated salts and Water of Crystallization

When ionic substances are dissolved in water to make their saturated aqueous solution, their ions attract water molecules which then attached chemically in certain ratio. This process is called hydration. These ionic substances crystallize out from their saturated aqueous solution with a definite number of molecules of water. The number of water molecules found in the crystalline substance is called **water of crystallization**. Such salts are called hydrated salts.

On heating these hydrated crystalline salts, they lose their water of crystallization and become amorphous or lose their colour (if they are coloured). Table 9.3 shows some common hydrated salts:

Table 9.3 Hydrated salts

Common Name	IUPAC Name	Molecular Formula
Blue Vitriol	Copper (II) sulphate pentahydrate	$CuSO_4{\cdot}5H_2O$
Epsom Salt	Magnesium sulphate heptahydrate	$MgSO_4{\cdot}7H_2O$
Gypsum	Calcium sulphate dihydrate	$CaSO_4{\cdot}2H_2O$
Green Vitriol	Iron (II) sulphate heptahydrate	$FeSO_4{\cdot}7H_2O$
White Vitriol	Zinc sulphate heptahydrate	$ZnSO_4{\cdot}7H_2O$

9.6.1 Copper sulphate pentahydrate $CuSO_4{\cdot}5H_2O$ (Blue vitriol)

The number of water molecules in blue vitriol is five. So its water of crystallization is 5. When blue coloured copper sulphate crystals are gently heated, it loses its five water molecules and becomes colourless anhydrous copper sulphate.

$$\underset{\substack{\text{(Copper sulphate}\\\text{pentahydrate)}\\\text{Blue colour}}}{CuSO_4{\cdot}5H_2O} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftharpoons}} \underset{\substack{\text{(Anhydrous copper}\\\text{sulphate)}\\\text{colourless}}}{CuSO_4 + 5H_2O}$$

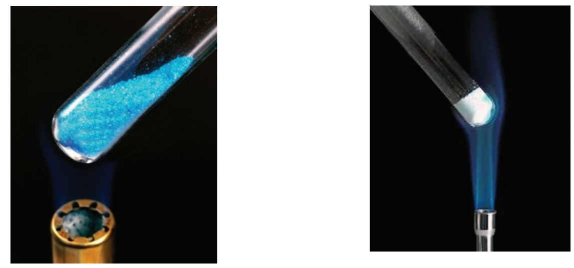


Figure 9.8 Copper sulphate heating before and after

If you add few drops of water or allow it to cool, the colourless anhydrous salt again turns back into blue coloured hydrated salt.

Figure 9.9 Hydrated copper sulphate and anhydrous copper sulphate

9.6.2 Magnesium sulphate heptahydrate $MgSO_4{\cdot}7H_2O$ (Epsom salt)

Its water of crystallization is 7. When magnesium sulphate heptahydrate crystals are gently heated, it loses seven water molecules, and becomes anhydrous magnesium sulphate.

$$\underset{\substack{\text{(Magnesium sulphate}\\\text{heptahydrate)}}}{MgSO_4{\cdot}7H_2O} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftharpoons}} \underset{\substack{\text{(Anhydrous Magnesium}\\\text{sulphate)}}}{MgSO_4 + 7H_2O}$$

Figure 9.10 Crystalline hydrated salt, Amorphous anhydrous salt

If you add few drops of water or allow it to cool, the colourless anhydrous salt again turns back into hydrated salt.

9.7 Hygroscopy

Certain substances, when exposed to the atmospheric air at ordinary temperature, absorb moisture without changing their physical state. Such substances are called **hygroscopic substances** and this property is called hygroscopy.

Hygroscopic substances are used as drying agents.

Example: 1. Conc.Sulphuric acid (H_2SO_4).
2. Phosphorus Pentoxide (P_2O_5).
3. Quick lime (CaO).
4. Silica gel (SiO_2).
5. Anhydrous calcium chloride ($CaCl_2$).

9.8 Deliquescence

Certain substances which are so hygroscopic, when exposed to the atmospheric air at ordinary temperatures, absorb enough water and get completely dissolved. Such substances are called **deliquescent substances** and this property is called **deliquescence**.

Deliquescent substances lose their crystalline shape and ultimately dissolve in the absorbed water forming a saturated solution.

Deliquescence is maximum when:

1) The temperature is low
2) The atmosphere is humid

Examples: Calcium chloride ($CaCl_2$), Caustic soda (NaOH), Caustic potash (KOH) and Ferric chloride ($FeCl_3$).

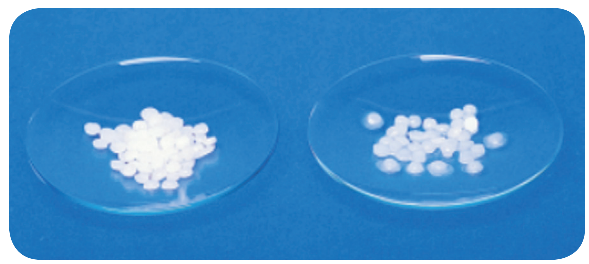


Figure 9.7 Deliquescence in Sodium hydroxide

9.9 Problems Based on Solubility and Percentage by Mass and Volume

I. Problems based on solubility

1) 1.5 g of solute is dissolved in 15 g of water to form a saturated solution at 298K. Find out the solubility of the solute at the temperature.

Table 9.3 Difference between hygroscopic substances and deliquescence.

Hygroscopic substances	Deliquescence substances
When exposed to the atmosphere at ordinary temperature, they absorb moisture and do not dissolve.	When exposed to the atmospheric air at ordinary temperature, they absorb moisture and dissolve.
Hygroscopic substances do not change its physical state on exposure to air.	Deliquescent substances change its physical state on exposure to air.
Hygroscopic substances may be amorphous solids or liquids.	Deliquescent substances are crystalline solids.

Mass of the solute = 1.5 g

Mass of the solvent = 15 g

$$\text{Solubility of the solute} = \frac{\text{Mass of the solute}}{\text{Mass of the solvent}} \times 100$$

$$\text{Solubility of the solute} = \frac{1.5}{15} \times 100$$

$$= 10 \text{ g}$$

2) Find the mass of potassium chloride would be needed to form a saturated solution in 60 g of water at 303 K? Given that solubility of the KCl is 37/100 g at this temperature.

Mass of potassium chloride in 100 g of water in saturated solution = 37 g

$$\text{Mass of potassium chloride in 60 g of water in saturated solution} = \frac{37}{100} \times 60$$

$$= 22.2 \text{ g}$$

3) What is the mass of sodium chloride that would be needed to form a saturated solution in 50 g of water at 30°C. Solubility of sodium chloride is 36 g at 30°C?

At 30°C, 36 g of sodium chloride is dissolved in 100 g of water.

∴ Mass of sodium chloride that would be need for 100 g of water = 36 g

$$\therefore \text{Mass of sodium chloride dissolved in 50 g of water} = \frac{36 \times 50}{100}$$

$$= 18 \text{ g}$$

4) The Solubility of sodium nitrate at 50°C and 30°C is 114 g and 96 g respectively. Find the amount of salt that will be thrown out when a saturated solution of sodium nitrate containing 50 g of water is cooled from 50°C to 30°C?

Amount of sodium nitrate dissolved in 100 g of water at 50°C is 114 g

$$\therefore \text{Amount of sodium nitrate dissolving in 50 g of water at 50°C is} = \frac{114 \times 50}{100}$$

$$= 57 \text{ g}$$

$$\text{Similarly amount of sodium nitrate dissolving in 50g of water at 30°C is} = \frac{96 \times 50}{100}$$

$$= 48\text{g}$$

Amount of sodium nitrate thrown when 50g of water is cooled from 50°C to 30°C is

$$57 - 48 = 9 \text{ g}$$

II. Problem based on mass percentage

1) A solution was prepared by dissolving 25 g of sugar in 100 g of water. Calculate the mass percentage of solute.

Mass of the solute = 25 g

Mass of the solvent = 100 g

$$\text{Mass Percentage} = \frac{\text{Mass of the sloute}}{\text{Mass of the solution}} \times 100$$

$$\text{Mass Percentage} = \frac{\text{Mass of the sloute}}{\text{Mass of the solute + Mass of the solvent}} \times 100$$

$$= \frac{25}{25+100} \times 100$$

$$= \frac{25}{125} \times 100$$

$$= 20\%$$

2) 16 grams of NaOH is dissolved in 100 grams of water at 25°C to form a saturated solution. Find the mass percentage of solute and solvent.

Mass of the solute (NaOH) = 16 g

Mass of the solvent H_2O = 100 g

(i) **Mass percentage of the solute**

$$\text{Mass percentage of solute} = \frac{\text{Mass of the solute}}{\text{Mass of the solute + Mass of the solvent}} \times 100$$

$$= \frac{16 \times 100}{16 + 100}$$

$$= \frac{1600}{116}$$

Mass percentage of the solute = 13.79 %

(ii) Mass percentage of solvent = 100 – (Mass percentage of the solute)

= 100 – 13.79

= 86.21%

3) Find the amount of urea which is to be dissolved in water to get 500 g of 10% w/w aqueous solution?

$$\text{Mass percentage (w/w)} = \frac{\text{Mass of the solute}}{\text{Mass of the solution}} \times 100$$

$$10 = \frac{\text{Mass of the urea}}{500} \times 100$$

Mass of urea = 50g

(iii) **Problem based on Volume – volume percentage.**

1) A solution is made from 35 ml of Methanol and 65 ml of water. Calculate the volume percentage.

Volume of the ethanol = 35 ml

Volume of the water = 65 ml

$$\text{Volume percentage} = \frac{\text{Volume of the solute}}{\text{Volume of the solution}} \times 100$$

$$\text{Volume percentage} = \frac{\text{Volume of the solute}}{\text{Volume of the solute} + \text{Volume of the solvent}} \times 100$$

$$\text{Volume percentage} = \frac{35}{35+65} \times 100$$

$$\text{Volume percentage} = \frac{35}{100} \times 100$$

$$= 35\%$$

2) Calculate the volume of ethanol in 200 ml solution of 20% v/v aqueous solution of ethanol.

Volume of aqueous solution = 200 ml

Volume percentage = 20%

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

$$20 = \frac{\text{Volume of ethanol}}{200} \times 100$$

$$\text{Volume of ethanol} = \frac{20 \times 200}{100} = 40 \text{ ml}$$

Points to Remember

- A solution is a homogeneous mixture of two or more substances.
- An aqueous solution is a solution in which the solvent is water.
- A non-aqueous solution is a solution in which the solvent is a liquid, other than water
- A solution in which no more solute can be dissolved in a definite amount of the solvent at a given temperature is called saturated solution.
- An unsaturated solution is one that contains less solute than the saturated solution at a given temperature.
- A supersaturated solution is one that contains more solute than the saturated solution at a given temperature.
- Polar compounds are soluble in polar solvents.
- Non-polar compounds are soluble in non-polar solvents.
- In endothermic process, solubility of solid solute increases with increase in temperature.
- In exothermic process, solubility of solid solute decreases with increase in temperature.

TEXTBOOK EVALUATION

G6DT3Y

I. Choose the correct answer.

1. A solution is a __________ mixture.
   a. homogeneous b. heterogeneous
   c. homogeneous and heterogeneous
   d. non homogeneous

2. The number of components in a binary solution is __________
   a. 2 b. 3
   c. 4 d. 5

3. Which of the following is the universal solvent?
   a. Acetone b. Benzene
   c. Water d. Alcohol

4. A solution in which no more solute can be dissolved in a definite amount of solvent at a given temperature is called _______
   a. Saturated solution
   b. Un saturated solution
   c. Super saturated solution
   d. Dilute solution

5. Identify the non aqueous solution.
   a. sodium chloride in water
   b. glucose in water
   c. copper sulphate in water
   d. sulphur in carbon-di-sulphide

6. When pressure is increased at constant temperature the solubility of gases in liquid __________.
   a. No change b. increases
   c. decreases d. no reaction

7. Solubility of NaCl in 100 ml water is 36 g. If 25 g of salt is dissolved in 100 ml of water how much more salt is required for saturation ____________.
   a. 12g b. 11g c. 16g d. 20g

8. A 25% alcohol solution means
   a. 25 ml alcohol in 100 ml of water
   b. 25 ml alcohol in 25 ml of water
   c. 25 ml alcohol in 75 ml of water
   d. 75 ml alcohol in 25 ml of water

9. Deliquescence is due to __________
   a. Strong affinity to water
   b. Less affinity to water
   c. Strong hatred to water
   d. Inertness to water

10. Which of the following is hygroscopic in nature?
    a. ferric chloride
    b. copper sulphate penta hydrate
    c. silica gel
    d. none of the above

II. Fill in the blanks

1. The component present in lesser amount, in a solution is called _______
2. Example for liquid in solid type solution is _____
3. Solubility is the amount of solute dissolved in _____ g of solvent.
4. Polar compounds are soluble in _____ solvents
5. Volume persentage decreases with increases in temperature because _____

III. Match the following

1. Blue vitriol	– $CaSO_4 \cdot 2H_2O$
2. Gypsum	– CaO
3. Deliquescence	– $CuSO_4 \cdot 5H_2O$
4. Hygroscopic	– NaOH

IV. True or False: (If false give the correct statement)

1. Solutions which contain three components are called binary solution.
2. In a solution the component which is present in lesser amount is called solvent.
3. Sodium chloride dissolved in water forms a non-aqueous solution.
4. The molecular formula of green vitriol is $MgSO_4 \cdot 7H_2O$
5. When Silica gel is kept open, it absorbs moisture from the air, because it is hygroscopic in nature

V. Short answer

1. Define the term: Solution
2. What is mean by binary solution
3. Give an example each i) gas in liquid ii) solid in liquid iii) solid in solid iv) gas in gas
4. What is aqueous and non-aqueous solution? Give an example.
5. Define Volume percentage
6. The aquatic animals live more in cold region Why?
7. Define Hydrated salt.
8. A hot saturated solution of copper sulphate forms crystals as it cools. Why?
9. Classify the following substances into deliquescent, hygroscopic.

   Conc. Sulphuric acid, Copper sulphate penta hydrate, Silica gel, Calcium chloride, and Gypsum salt.

VI. Long answer:

1. Write notes on i) saturated solution ii) unsaturated solution
2. Write notes on various factors affecting solubility.
3. a) What happens when $MgSO_4 \cdot 7H_2O$ is heated? Write the appropriate equation

   b) Define solubility
4. In what way hygroscopic substances differ from deliquescent substances.
5. A solution is prepared by dissolving 45 g of sugar in 180 g of water. Calculate the mass percentage of solute.
6. 3.5 litres of ethanol is present in 15 litres of aqueous solution of ethanol. Calculate volume percent of ethanol solution.

VII. HOT

1. Vinu dissolves 50 g of sugar in 250 ml of hot water, Sarath dissolves 50 g of same sugar in 250 ml of cold water. Who will get faster dissolution of sugar? and Why?
2. 'A' is a blue coloured crystaline salt. On heating it loses blue colour and to give 'B'. When water is added, 'B' gives back to 'A'. Identify A and B, write the equation.
3. Will the cool drinks give more fizz at top of the hills or at the foot? Explain

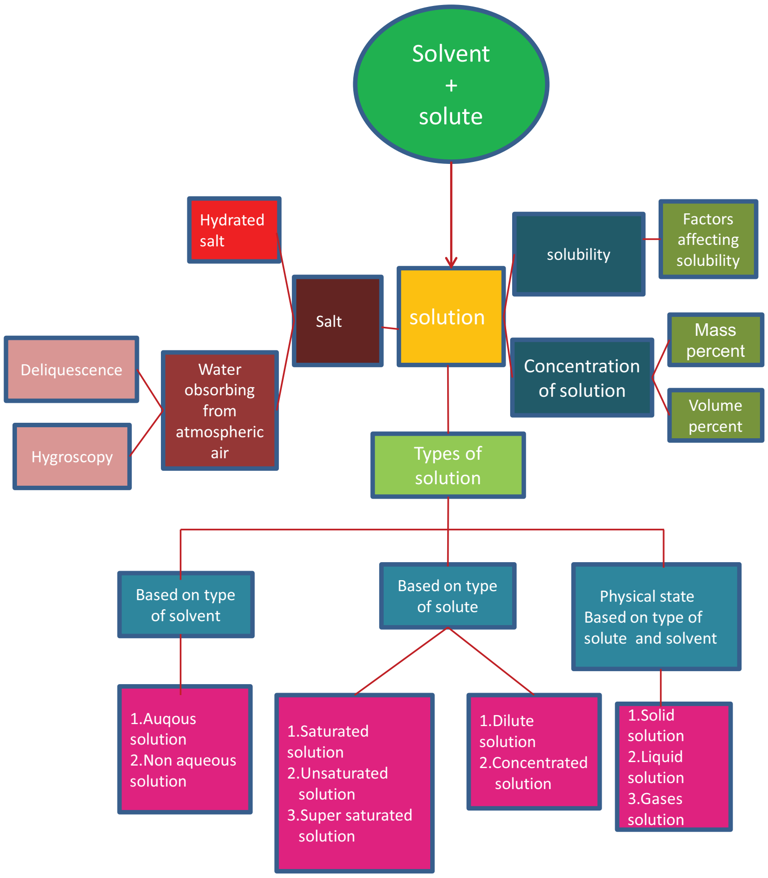
REFERENCE BOOKS

1. Properties Liquids Solutions John Murrell 2nd Edition.
2. Fundamental Interrelationships Between Certain Soluble Salts and Soil Colloids (Classic Reprint) Hardcover, by Leslie Theodore Sharp

INTERNET RESOURCES

1. https://www.cwcboe.org/cms/lib/NJ01001185/Centricity/Domain/203/Solutions%20Suspensions%20and%20Colloids.pdf

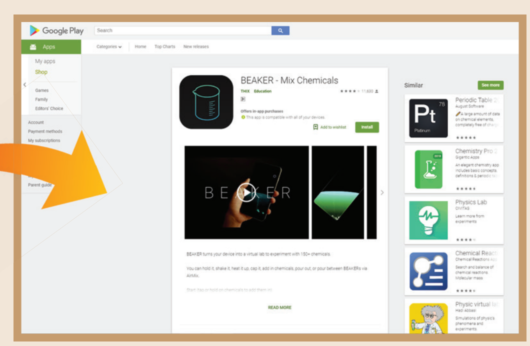
Concept Map



ICT CORNER

Solutions

BEAKER application enable the students to use their mobile as virtual chemistry laboratory and also to do various experiments on their own.



Steps

- Access the application "BEAKER – Mix Chemicals" with help of the URL or QR code, Install it in the mobile. You can see that the screen will act like a beaker after opening the application.
- If you click the round button, you can see many elements and compounds.
- If you click any elements and compounds, it will be added to the beaker in the home screen.
- By clicking Menu at the left side, You can see lid, match stick, burner and chemist. Use those whenever necessary.

URL: https://play.google.com/store/apps/details?id=air.thix.sciencesense.beaker

or Scan the QR Code.

B375_10_SCIENCE_EM

UNIT 10

TYPES OF CHEMICAL REACTIONS

GKWN5A

Learning Objectives

After completing this lesson learners will be able to

- infer different types of chemical reaction.
- acquire knowledge about combination reaction and skill to perform a combination reaction using quick lime and water.
- identify and differentiate between reversible and irreversible reactions.
- explain the reversible reaction occurring at the equilibrium state.
- list and explain characteristics of equilibrium state.
- define rate of reaction.
- discuss the dependence of rate of reactions on concentration, temperature and catalyst.
- define pH.
- correlate the concentration of hydrogen ions and pH with neutral, acidic and basic nature of aqueous solutions.
- recognize the importance of pH in everyday life.
- explain the term ionic product of water.

INTRODUCTION

As you know from your earlier studies, a chemical reaction involves breaking of old chemical bonds and formation of new chemical bonds. This change may happen spontaneously or it may be facilitated by external forces or energy. Chemistry is all about chemical reactions. In your day to day life, you could observe many chemical reactions. A clear understanding of these reactions is essential in order to manipulate them for the sake of human life and environment. So, chemistry mainly focuses on chemical reactions. Let us try to find the answer for the following questions:

- You need energy to play, walk, run or to perform various physical activities. Where do you get the energy from?
- How do plants grow and get their food?
- How does a car move using fuel?
- Why does iron rust on its exposure to water or air?

You get energy from the digestion of the food you eat. Plants grow by absorbing nutrients from the Earth and get their food by photosynthesis. The combustion of a fuel makes the car to move. Oxidation of iron causes rusting. So, all these processes are chemical changes i.e. the materials, which undergo changes are converted into some other new materials. For example, by burning petrol, the hydrocarbons present in it are converted into carbon dioxide and water. In this chapter, let us discuss the nature and types of chemical reactions.

What happens during a chemical reaction?

- In a chemical reaction, the atoms of the reacting molecules or elements are rearranged to form new molecules.
- Old chemical bonds between atoms are broken and new chemical bonds are formed.
- Bond breaking absorbs energy whereas bond formation releases energy

How are chemical reactions represented?

When methane reacts with oxygen, it forms carbon dioxide and water. How can you represent this reaction? It can be written as a word equation as shown below:

Methane + Oxygen → Carbon dioxide + Water

But, this equation does not give the chemical composition of the reactants and products. So, to learn the characteristics of a chemical reaction, it is represented by a chemical equation. In the chemical equation, the chemicals of the reaction are represented by their chemical formulas.The compounds or elements, which undergo reactions (reactants) are shown to the left of an arrow and the compounds formed (products) are shown to the right of the arrow. The arrow indicates the direction of the reaction. Thus, the aforesaid reaction can be written as follows:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

But, this is also an incomplete chemical equation. Because, the law of conservation of matter states that matter cannot be created or destroyed. You cannot create new atoms by a chemical reaction. In contrast, they are rearranged in different ways by a chemical reaction to form a new compound. So, in a chemical equation, the number of atoms of the reactants and that of the products must be equal. The number of hydrogen and oxygen atoms in the reactants and the products are not equal in the given equation. On balancing the number of atoms, the following equation can be obtained:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Further, the chemical equation provides information on the physical state of the substances and the conditions under which the reaction takes place.

$$\underset{\text{Methane}}{CH_{4(g)}} + \underset{\text{Oxygen}}{2O_{2(g)}} \rightarrow \underset{\text{Carbon dioxide}}{CO_{2(g)}} + \underset{\text{Water}}{2H_2O_{(g)}}$$

A balanced chemical equation is the simplified representation of a chemical reaction which describes the chemical composition, physical state of the reactants and the products, and the reaction conditions.

MORE TO KNOW

The phases or the physical state of the substances in a chemical reaction are denoted in short form within a bracket, as the subscript of the formula, of the respective substances. For example, when solid potassium reacts with liquid water, it produces hydrogen gas and potassium hydroxide solution. All these information of the reaction is given in the chemical equation as shown below:

$$2K_{(s)} + 2H_2O_{(l)} \rightarrow 2KOH_{(aq)} + H_{2(g)}$$

Symbol	Phase or physical state
s	Solid
l	Liquid
g	Gas
aq	Aqueous Solution

10.1 TYPES OF CHEMICAL REACTIONS

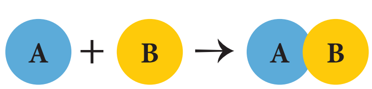
Classification based on the nature of rearrangements of atoms

So far you studied about a chemical reaction and how it can be described as a chemical equation. A large number of chemical reactions are taking place around us every day. Are they taking place in a similar way? No. Each reaction involves different kinds of atoms and hence the way they react also differs. Thus, based on the manner by which the atoms of the reactants are rearranged, chemical reactions are classified as follows.

H1FI6L

(a) Combination reactions

A combination reaction is a reaction in which two or more reactants combine to form a compound. It is otherwise called 'synthesis reaction' or 'composition reaction'. When a reactant 'A' combines with 'B', it forms the product 'AB'. The generalised scheme of a combination reaction is given below:



Example: Hydrogen gas combines with chlorine gas to form hydrogen chloride gas.

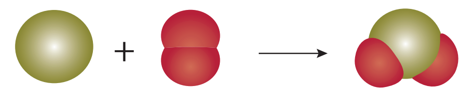
$$H_{2(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)}$$

Depending on the chemical nature of the reactants, there are **three classes** of combination reactions:

❖ **Element + Element → Compound**

In this type of combination reaction, two elements react with one other to form a compound. The reaction may take place between a metal and a non-metal or two non-metals.

Example 1: When solid sulphur reacts with oxygen, it produces sulphur dioxide. Here both the reactants are non-metals.



$$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$$

Example 2: Sodium, a silvery-white metal, combines with chlorine, a pale yellow green gas, to form sodium chloride, an edible compound. Here one of the reactants is a metal (sodium) and the other (chlorine) is a non-metal.

$$2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$$

Test Yourself:

Identify the possible combination reactions between the metals and non-metals given in the following table and write their balanced chemical equations:

Metals	Non-metals
Na, K, Cs, Ca, Mg	F, Cl, Br, I

❖ **Compound + Element → Compound**

In this case, a compound reacts with an element to form a new compound. For instance, phosphorous trichloride reacts with chlorine gas and forms phosphorous pentachloride.

$$PCl_{3(l)} + Cl_{2(g)} \rightarrow PCl_{5(s)}$$

❖ **Compound + Compound → Compound**

It is a reaction between two compounds to form a new compound. In the following reaction, silicon dioxide reacts with calcium oxide to form calcium silicate.

$$SiO_{2(s)} + CaO_{(s)} \rightarrow CaSiO_{3(s)}$$

Most of the combination reactions are exothermic in nature. Because, they involve the formation of new bonds, which releases a huge amount of energy in the form of heat.

(b) Decomposition reactions

In a decomposition reaction, a single compound splits into two or more simpler substances under suitable conditions. It is the opposite of the combination reaction. The **generalised scheme** of a decomposition reaction is given below:

Breaking of bonds is the major phenomenon in a decomposition reaction and hence it requires energy to break the bonds, depending on the nature of the energy used in the decomposition reaction.

There are three main classes of decomposition reactions. They are

(i) Thermal Decomposition Reactions

(ii) Electrolytic Decomposition Reactions

(iii) Photo Decomposition Reactions

> **DO YOU KNOW?**
>
> A solution of slaked lime is used for white washing walls. Calcium hydroxide reacts slowly with the carbon dioxide in air to form a thin layer of calcium carbonate on the walls. Calcium carbonate is formed after two to three days of white washing and gives a shiny finish to the walls. It is interesting to note that the **chemical formula for marble is also** $CaCO_3$
>
> $$\underbrace{Ca(OH)_{2(aq)}}_{\text{Slaked Lime}} + \underbrace{CO_{2(g)}}_{\text{Carbon dioxide}} \rightarrow \underbrace{CaCO_{3(s)}}_{\text{Calcium Carbonate}} + \underbrace{H_2O_{(l)}}_{\text{Water}}$$

(i) Thermal Decomposition Reactions

In this type of reaction, the reactant is decomposed by applying heat. For example, on heating mercury (II) oxide is decomposed into mercury metal and oxygen gas. As the molecule is dissociated by the absorption of heat, it is otherwise called **'Thermolysis'.** It is a class of compound to element/element decomposition. i.e. a compound (HgO) is decomposed into two elements (Hg and Oxygen).

$$2HgO_{(s)} \xrightarrow{\text{Heat}} 2Hg_{(l)} + O_{2(g)}$$

Similarly, when calcium carbonate is heated, it breaks down in to calcium oxide and carbon dioxide. It is a type of compound to compound/compound decomposition.

$$CaCO_{3(s)} \xrightarrow{\text{Heat}} CaO_{(s)} + CO_{2(g)}$$

In thermal decomposition reaction, heat is supplied to break the bonds. Such reactions, in which heat is absorbed, are called **'Endothermic reactions'**.

(ii) Electrolytic Decomposition Reactions

In some of the decomposition reactions, electrical energy is used to bring about the reaction. For example, decomposition of sodium chloride occurs on passing electric current through its aqueous solution. Sodium chloride decomposes in to metallic sodium and chlorine gas. This process is termed as 'Electrolysis'.

$$2NaCl_{(aq)} \xrightarrow{\text{Electricity}} 2Na_{(s)} + Cl_{2(g)}$$

Here, a compound (NaCl) is converted into elements (Na and chlorine). So it is a type of compound to element/element decomposition.

(iii) Photo Decomposition Reactions

Light is an another form of energy, which facilitates some of the decomposition reactions. For example, when silver bromide is exposed to light, it breaks down into silver metal and bromine gas. As the decomposition is caused by light, this kind of reaction is also called **'Photolysis'.**

$$2AgBr_{(s)} \xrightarrow{\text{Light}} 2Ag_{(s)} + Br_{2(g)}$$

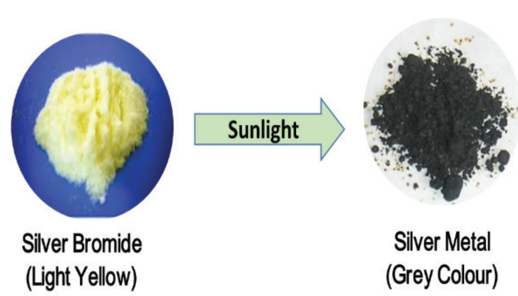
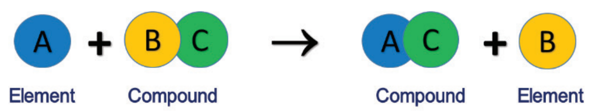


Figure 10.1 Photo decomposition of silver bromide

The yellow coloured silver bromide turns into grey coloured silver metal. It is also a compound to element/element decomposition.

(c) Single Displacement Reactions

It is a reaction between an element and a compound. When they react, one of the elements of the compound-reactant is replaced by the element-reactant to form a new compound and an element. The general schematic representation of a single displacement reaction is given as:



'A' displaces element 'B' from the compound 'BC' and hence a single displacement reaction occurs. If zinc metal is placed in hydrochloric acid, hydrogen gas is evolved. Here, hydrogen is displaced by zinc metal and zinc chloride is formed.

$$Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$$

$$Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}$$

If an iron nail is placed in an aqueous solution of copper (II) sulphate as shown in Fig. 10.2, the iron displaces copper from its aqueous solution and the so formed copper deposits over the iron nail.

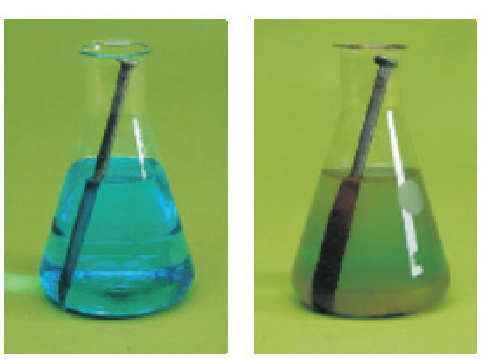


Figure 10.2 Displacement of copper

It is easy to propose so many reactions of this kind with different combinations of reactants. Will they all occur in practice? No. This is most easily demonstrated with halogens. Let us consider the following two reactions:

$$2NaCl_{(aq)} + F_{2(g)} \rightarrow 2NaF_{(aq)} + Cl_{2(g)}$$

$$2NaF_{(aq)} + Cl_{2(g)} \rightarrow 2NaCl_{(aq)} + F_{2(g)}$$

The first reaction involves the displacement of chlorine from NaCl, by fluorine. In the second reaction, chlorine displaces fluorine from NaF. Out of these two, the second reaction will not occur. Because, fluorine is more active than chlorine and occupies the upper position in the periodic table. So, in displacement reactions, the activity of the elements and their relative position in the periodic table are the key factors to determine the feasibility of the reactions. More active elements readily displace less active elements from their aqueous solution.

The activity series of some elements is given below:

To remember ↓	Activity Series ↓	
Please	Potassium (K)	↑ Most reactive
Send	Sodium (Na)	
Lions	Lithium (Li)	
Cats	Calcium (Ca)	
Monkeys	Magnesuim (Mg)	
And	Aluminium (Al)	
Zebras	Zinc (Zn)	
Into	Iron (Fe)	
Lovely	Lead (Pb)	
Hot	Hydrogen (H) non-metal	
Countries	Copper (Cu)	
Signed	Silver (Ag)	
General	Gold (Au)	
Penguin	Platinum (Pt)	Least reactive

By referring the activity series, try to answer the following questions:

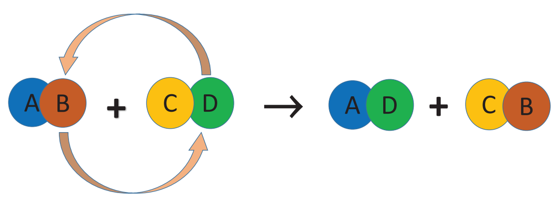
Which of the metals displaces hydrogen gas from hydrochloric acid? Silver or Zinc. Give the chemical equation of the reaction and Justify your answer.

Activity 10.1

- Take about 50 ml of toilet cleaning acid in a beaker
- Place a small iron nail in it
- Wait for about 10 minutes
- Observe what happen in the beaker
- Do you recognize any change?
- Report your observations with the chemical equation.

(d) Double Displacement Reactions

When two compounds react, if their ions are interchanged, then the reaction is called double displacement reaction. The ion of one compound is replaced by the ion of the another compound. Ions of identical charges are only interchanged, i.e., a cation can be replaced by other cations. This reaction is also called '**Metathesis Reaction**'. The schematic representation of a double displacement reaction is given below:



For a double displacement reaction to take place, one of the products must be a precipitate or water. By this way, there are major classes of double displacement reactions. They are:

(i) Precipitation Reactions

(ii) Neutralization Reactions

(i) Precipitation Reactions

When aqueous solutions of two compounds are mixed, if they react to form an insoluble compound and a soluble compound, then it is called precipitation reaction. Because the insoluble compound, formed as one of the products, is a precipitate and hence the reaction is so called.

Table 10.1 Differences between combination and decomposition reactions

COMBINATION REACTIONS	DECOMPOSITION REACTIONS
One or more reactants combine to form a single product	A single reactant is decomposed to form one or more products
Energy is released	Energy is absorbed
Elements or compounds may be the reactants	Single compound is the reactant

When the clear aqueous solutions of potassium iodide and lead (II) nitrate are mixed, a double displacement reaction takes place between them.

$$Pb(NO_3)_{2(aq)} + 2KI_{(aq)} \rightarrow PbI_{2(s)}\downarrow + 2KNO_{3(aq)}$$

Potassium and lead displace or replace one other and form a yellow precipitate of lead (II) iodide as shown in Fig. 10.3.

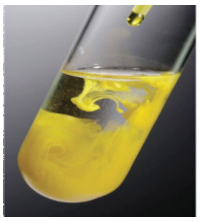


Figure 10.3 Precipitation of PbI_2

Activity 10.2

- Take a pinch of silver nitrate crystals.
- Collect about 5 ml of tap water in a test tube.
- Add the silver nitrate crystals to water and shake well.
- Observe what happen in the test tube.
- Report your observations and what you infer from that?

(ii) Neutralization Reactions

In your lower classes, you have learned the reaction between an acid and a base. It is another type of displacement reaction in which the acid reacts with the base to form a salt and water. It is called 'neutralization reaction' as both acid and base neutralize each other.

Acid + Base → Salt + Water

Reaction of sodium hydroxide with hydrochloric acid is a typical neutralization reaction. Here, sodium replaces hydrogen from hydrochloric acid forming sodium chloride, a neutral soluble salt.

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

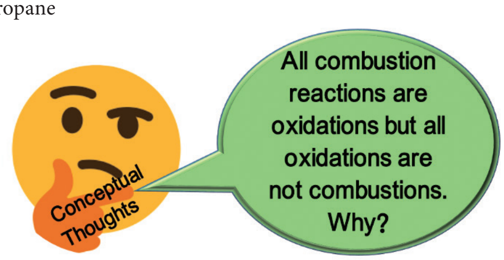
Similarly, when ammonium hydroxide reacts with nitric acid, it forms ammonium nitrate and water.

$$HNO_{3(aq)} + NH_4OH_{(aq)} \rightarrow NH_4NO_{3(aq)} + H_2O_{(l)}$$

(e) Combustion Reactions

A combustion reaction is one in which the reactant rapidly combines with oxygen to form one or more oxides and energy (heat). So in combustion reactions, one of the reactants must be oxygen. Combustion reactions are majorly used as heat energy sources in many of our day to day activities. For instance, we use LPG gas for domestic cooking purposes. We get heat and flame from LPG gas by its combustion reaction of its constituent gases. LPG is a mixture of hydrocarbon gases like propane, butane, propylene, etc. All these hydrocarbons burn with oxygen to form carbon dioxide and water.

$$\underset{\text{Propane}}{C_3H_{8(g)}} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(g)} + \text{Heat}$$



Since heat is evolved, it is an exothermic reaction. As oxygen is added, it is also an oxidation. So, combustion may be called as an exothermic oxidation. If a flame is formed (as shown in Fig. 10.4), then it is called **burning**.

Figure 10.4 Combustion of LPG gas

Which of the following is a combustion?

(i) Digestion of Food

(ii) Rusting of iron

Many thousands of reactions fall under these five categories and further you will learn in detail about these reactions in your higher classes.

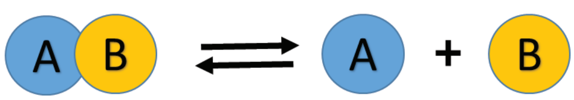
10.1.2 Classification based on the direction of the reaction

You know that innumerable changes occur every day around us. Are all they permanent? For example, liquid water freezes into ice, but then ice melts into liquid water. In other words, freezing is reversed. So, it is not a permanent change. Moreover, it is a physical change. Physical changes can be reversed easily. Can chemical changes be reversed? Can the products be converted into reactants? Let us consider the burning of a wood. The carbon compounds present in the wood are burnt into carbon dioxide gas and water. Can we get back the wood immediately from carbon dioxide and water? We cannot. So, it is a permanent change. In most of the cases, we cannot. But, some chemical reactions can be reversed. Our mobile phone gets energy from its lithium ion battery by chemical reactions. It is called discharging. On recharging the mobile, these chemical reactions are reversed. Thus, chemical reactions may be reversed under suitable conditions. Hence, they are grouped into two categories such as reversible and irreversible reactions.

Figure 10.5 Burning of wood and recharging of mobile battery

Reversible Reactions

A reversible reaction is a reaction that can be reversed, i.e., the products can be converted back to the reactants. A reversible reaction is represented by a double arrow with their heads in the direction opposite to each other. Thus, a reversible reaction can be represented by the following equation:



Explanation: Here, the compound 'AB' undergoes decomposition to form the products 'A' and 'B'. It is the **forward reaction**. As soon as the products are formed, they combine together to form 'AB'. It is the **backward reaction**. So, the reaction takes place in both the directions. Do you think then that no products are formed in the aforesaid reaction? If you think so, you are wrong. Because, even though the reaction takes place in both the directions, at the initial stage the rates (speed) of these reactions are not equal. Consider the following decomposition reaction of phosphorous pentachloride into phosphorous trichloride and chlorine.

$$PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}$$

The forward reaction is the decomposition of PCl_5 and the backward reaction is the combination of PCl_3 and Cl_2. Initially, the forward reaction proceeds faster than the backward reaction. After sometimes, the speed of both the reactions become equal. So, PCl_5 cannot be completely converted into the products as the reaction is reversed. It is a reversible reaction. The actual measurements of the given reaction show that the reaction is at equilibrium, but the amount of PCl_5 is more than that of PCl_3 and Cl_2.

MORE TO KNOW

If hydrogen peroxide is poured on a wound, it decomposes into water and oxygen. The gaseous oxygen bubbles away as it is formed and thus prevent the formation of H_2O_2.

Hydrogen peroxide on a wound

Thus, more amount of products can be obtained in a reversible reaction by the periodical removal of one of the products or the periodical addition of the reactants.

$$2H_2O_{2(aq)} \rightleftharpoons 2H_2O_{(l)} + O_{2(g)}$$

Irreversible Reactions

The reaction that cannot be reversed is called **irreversible reaction**. The irreversible reactions are unidirectional, i.e., they take place only in the forward direction. Consider the combustion of coal into carbon dioxide and water.

$$\underset{\text{Coal}}{C_{(s)}} + \underset{\text{Oxygen}}{O_{2(g)}} \rightarrow \underset{\text{Carbon dioxide}}{CO_{2(g)}} + \text{Heat}$$

In this reaction, solid coal burns with oxygen and gets converted into carbon dioxide gas and water. As the product is a gas, as soon as it is formed it escapes out of the reaction container. It is extremely hard to decompose a gas into a solid. Thus, the backward reaction is not possible in this case. So, it is an irreversible reaction. Table 10.2 provides the main differences between a reversible and an irreversible reaction:

Table 10.2 Differences between reversible and irreversible reactions

REVERSIBLE REACTION	IRREVERSIBLE REACTION
It can be reversed under suitable conditions.	It cannot be reversed.
Both forward and backward reactions take place simultaneously.	It is unidirectional. It proceeds only in forward direction.
It attains equilibrium.	Equilibrium is not attained.
The reactants cannot be converted completely into products.	The reactants can be completely converted into products.
It is relatively slow.	It is fast.

You will learn more about these reactions in your higher classes.

10.2 RATE OF A CHEMICAL REACTION

So far we discussed various types of chemical reactions and the nature of the reactants and products. Let us consider the following reactions:

- Rusting of iron
- Digestion of food
- Burning of petrol
- Weathering of rock

How fast is each reaction? Rank them from the slowest to fastest. How will you determine, which is the fastest and which is the slowest? One of the ways to find out how fast a reaction is as follows: Measure the amount of reactants or products before and after a specific period of time. For example, let us assume that 100 g of a substance 'A' undergoes a reaction and after an hour 50 g of 'A' is left.

$$A \rightarrow \text{Product}$$

In another instance, 100 g of substance 'C' undergoes a reaction and after an hour, 20 g of 'C' is left.

$$C \rightarrow \text{Product}$$

Can you say which is the faster reaction? In the first reaction, 50 g of the reactant (A) is converted into products whereas in the second reaction 80 g of the reactant is converted into products in one hour. So, the second reaction is faster. This measurement is called 'the reaction rate'.

"Rate of a reaction is the change in the amount or concentration of any one of the reactants or products per unit time".

Consider the following reaction

$$A \rightarrow B$$

The rate of this reaction is given by

$$\text{Rate} = -\frac{d[A]}{dt} = +\frac{d[B]}{dt}$$

Where,

[A] – Concentration of A

[B] – Concentration of B

The negative sign indicates the decrease in the concentration of A with time.

The postive sign indicates the increase in the concentration of B with time.

Note: '[ ]' represents the concentration, 'd' represents the infinitesimal change in the concentration.

Why is reaction rate important?

Faster the reaction, more will be the amount of the product in a specified time. So, the rate of a reaction is important for a chemist for designing a process to get a good yield of a product. Rate of reaction is also important for a food processor who hopes to slow down the reactions that cause food to spoil.

10.2.1 Factors influencing the rate of a reaction

Can the rate of a reaction be changed? The rate of a reaction can be changed. For example, iron gets rusted faster in an acid than in water. Important factors that affect rate of a reaction are

(i) Nature of the reactants
(ii) Concentration of the reactants
(iii) Temperature
(iv) Catalyst
(v) Pressure
(vi) Surface area of the reactants

(i) Nature of the reactants

The reaction of sodium with hydrochloric acid is faster than that with acetic acid. Do you know why? Hydrochloric acid is a stronger acid than acetic acid and thus more reactive. So, the nature of the reactants influence the reaction rate.

$$2Na_{(s)} + 2HCl_{(aq)} \longrightarrow 2NaCl_{(aq)} + H_{2\,(g)} \text{ (fast)}$$
$$2Na_{(s)} + 2CH_3COOH_{(aq)} \longrightarrow 2CH_3COONa_{(aq)} + H_{2(g)} \text{(slow)}$$

(ii) Concentration of the reactants

Changing the amount of the reactants also increases the reaction rate. The amount of the substance present in a certain volume of the solution is called **'concentration'**. More the concentration, more particles per volume exist in it and hence faster the reaction. Granulated zinc reacts faster with 2M hydrochloric acid than 1M hydrochloric acid.

(iii) Temperature

Most of the reactions go faster at higher temperature. Because adding heat to the reactants provides energy to break more bonds and thus speed up the reaction. Calcium carbonate reacts slowly with hydrochloric acid at room temperature. When the reaction mixture is heated the reaction rate increases.

> **DO YOU KNOW?** Food kept at room temperature spoils faster than that kept in the refrigerator. In the refrigerator, the temperature is lower than the room temperature and hence the reaction rate is less.

(iv) Pressure

If the reactants are gases, increasing their pressure increases the reaction rate. This is because, on increasing the pressure the reacting particles come closer and collide frequently.

(v) Catalyst

A catalyst is a substance which increases the reaction rate without being consumed in the reaction. In certain reactions, adding a substance as catalyst speeds up the reaction. For example, on heating potassium chlorate, it decomposes into potassium chloride and oxygen gas, but at a slower rate. If manganese dioxide is added, it increases the reaction rate.

(vi) Surface area of the reactants

When solid reactants are involve in a reaction, their powdered form reacts more readily. For example, powdered calcium carbonate reacts more readily with hydrochloric acid than marble chips. Because, powdering of the reactants increases the surface area and more energy is available on collision of the reactant particles. Thus, the reaction rate is increased.

You will study more about reaction rate in you higher classes.

10.3 STATE OF EQUILIBRIUM

In a reversible reaction, both forward and backward reactions take place simultaneously. When the rate of the forward reaction becomes equal to the rate of backward reaction, then no more product is formed. This stage of the reaction is called **'equilibrium state'**. After this stage, no net change in the reaction can occur and hence in the amount of the reactants and products. Since this equilibrium is attained in a chemical reaction, it is called 'Chemical Equilibrium'. **Chemical Equilibrium: It is state of a reversible chemical reaction in which no change in the amount of the reactants and products takes place. At equilibrium,**

Rate of forward reaction = Rate of backward reaction

Explanation: Initially the rate of the forward reaction is greater than the rate of the backward reaction. However, during the course of reaction, the concentration of the reactants decreases and the concentration of the products increases. Since the rate of a reaction is directly proportional to the concentration, the rate of the forward reaction decreases with time, whereas the rate of the backward reaction increases.

At a certain stage, both the rates become equal. From this point onwards, there will be no change in the concentrations of both the reactants and the products with time. This state is called as equilibrium state.

Let us consider the decomposition of calcium carbonate into lime and carbon dioxide. It is a reversible reaction. The speed of each reaction can be determined by how quickly the reactant disappears. If the reaction is carried out in a closed vessel, it reaches a chemical equilibrium. At this stage,

$$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$$

The rate of decomposition of $CaCO_3$ = The rate of combination of CaO and CO_2

Not only chemical changes, physical changes also may attain equilibrium. When water kept in a closed vessel evaporates, it forms water vapour. No water vapour escapes out of the container as the process takes place in a closed vessel. So, it builds up the vapour pressure in the container. At one time, the water vapour condenses back into liquid water and when the rate of this condensation becomes equal to that of vapourisation, the process attains equilibrium.

At this stage, the volume of the liquid and gaseous phases remain constant. Since it is a physical change, the equilibrium attained is called **'Physical Equilibrium'.** Physical equilibrium is a state of a physical change at which the volume of all the phases remain unchanged.

$$H_2O_{(l)} \underset{\text{Condensation}}{\overset{\text{Evaporation}}{\rightleftharpoons}} H_2O_{(g)}$$

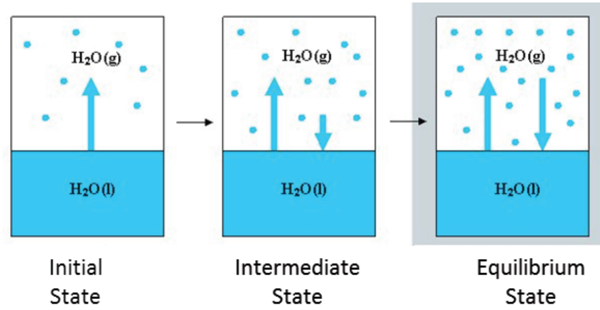


Figure 10.6 State of physical equilibrium

Characteristics of equilibrium

- In a chemical equilibrium, the rates of the forward and backward reactions are equal.
- The observable properties such as pressure, concentration, colour, density, viscosity etc., of the system remain unchanged with time.
- The chemical equilibrium is a dynamic equilibrium, because both the forward and backward reactions continue to occur even though it appears static externally.
- In physical equilibrium, the volume of all the phases remain constant.

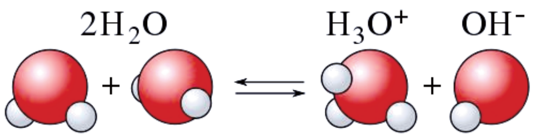
DO YOU KNOW?

Aerated soft drinks contain dissolved carbon dioxide in a pop bottle (Soda). When the bottle is sealed, the dissolved carbon dioxide (in the form of carbonic acid) and gaseous CO_2 are in equilibrium with each other. When you open the bottle, the gaseous CO_2 can escape. So, the dissolved CO_2 begins to undissolve back to the gas phase trying to replace the gas that was lost, when you opened the bottle. That's why if you leave it open long enough, it will goes 'flat'. All the CO_2 will be gone, blown away in the air.

10.4 IONIC PRODUCT OF WATER

Although pure water is often considered as a non-conductor of electricity, precise measurements show that it conducts electricity to a little extent. This conductivity of water has resulted from the self-ionisation of water. Self-ionisation or auto ionisation is a reaction in which two like molecules react to give ions. In the process of ionisation of water, a proton from one water molecule is transferred to another water molecule leaving behind an OH^- ion. The proton gets dissolved in water forming the hydronium ion as shown in the following equation:

$$H_2O_{(l)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$$



The hydronium ion formed is a strong acid and the hydroxyl ion is a strong base. So as fast as they are formed, they react again to produce water. Thus, it is a reversible reaction and attains equilibrium very quickly. So, the extent of ionisation is very little and the concentration of the ions produced is also very less. The product of the concentration of the hydronium ion and the hydroxyl ion is called **'ionic product of water'**. It is denoted as **'K_w'**. It is mathematically expressed as follows:

$$K_w = [H_3O^+]\ [OH^-]$$

$[H_3O^+]$ may be simply written as $[H^+]$. Thus the ionic product of water may also be expressed as

$$K_w = [H^+]\ [OH^-]$$

Its unit is $mol^2\ dm^{-6}$. At 25° C, its value is 1.00×10^{-14}.

10.5 pH SCALE

All the aqueous solutions may contain hydrogen and hydroxyl ions due to self-ionisation of water. In addition to this ionisation, substances dissolved in water also may produce hydrogen ions or hydroxyl ions. The concentration of these ions decides whether the solution is acidic or basic. pH scale is a scale for measuring the hydrogen ion concentration in a solution. The 'p' in pH stands for 'Potenz' in German meaning 'power'. pH notation was devised by the Danish biochemist Sorensen in 1909. pH scale is a set of numbers from 0 to 14 which is used to indicate whether a solution is acidic, basic or neutral.

- ✓ Acids have pH less than 7
- ✓ Bases have pH greater than 7
- ✓ A neutral solution has pH equal to 7

The pH is the negative logarithm of the hydrogen ion concentration

i.e $pH = -\log_{10}[H^+]$

COMMON ACIDS	pH	COMMON BASES	pH
HCl (4%)	0	Blood plasma	7.4
Stomach acid	1	Egg white	8
Lemon juice	2	Sea water	8
Vinegar	3	Baking soda	9
Oranges	3.5	Antacids	10
Soda, grapes	4	Ammonia water	11
Sour milk	4.5	Lime water	12
Fresh milk	5	Drain cleaner	13
Human saliva	6-8	Caustic soda 4% (NaOH)	14
Pure water	7	Milk of magnesia	10
Tomato juice	4.2	Coffee	5.6

How can we measure the pH of a given solution using pH Paper

The pH of a solution can be determined by using a universal indicator. It contains a mixture of dyes. It comes in the form of a solution or a pH paper.

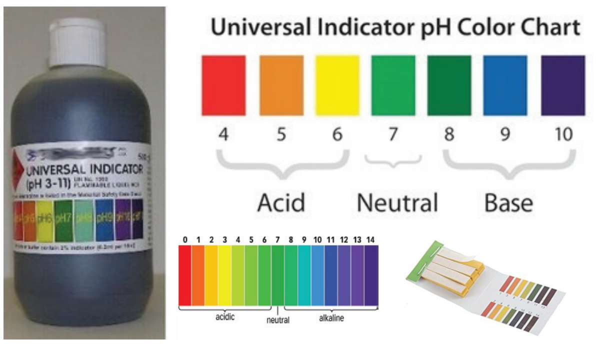


Figure 10.7 pH Indicator

A more common method of measuring pH in a school laboratory is by using the pH paper. A pH paper contains a mixture of indicators. It shows a specific colour at a given pH. A colour guide is provided with the bottle of the indicator or the strips of paper impregnated with it, which are called pH paper strips. The test solution is tested with a drop of the universal indicator, or a drop of the test solution is put on the pH paper. The colour of the solution on the pH paper is compared with the colour chart and the pH value is read from it. The pH values thus obtained are only approximate values.

10.6 ROLE OF pH IN EVERYDAY LIFE

Are plants and animals pH sensitive?

Our body works within the pH range of 7.0 to 7.8. Living organisms can survive only in a narrow range of pH change. Different body fluids have different pH values. For example, pH of blood is ranging from 7.35 to 7.45. Any increase or decrease in this value leads to diseases. The ideal pH for blood is 7.4.

pH in our digestive system

It is very interesting to note that our stomach produces hydrochloric acid. It helps in the digestion of food without harming the stomach. During indigestion the stomach produces too much acid and this causes pain and irritation. pH of the stomach fluid is approximately 2.0.

pH changes as the cause of tooth decay

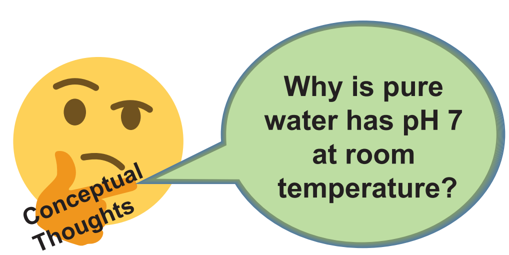
pH of the saliva normally ranges between 6.5 to 7.5. White enamel coating of our teeth is calcium phosphate, the hardest substance in our body. When the pH of the mouth saliva falls below 5.5, the enamel gets weathered. Toothpastes, which are generally basic are used for cleaning the teeth that can neutralise the excess acid and prevent tooth decay.

pH of soil

In agriculture, the pH of the soil is very important. Citrus fruits require slightly alkaline soil, while rice requires acidic soil and sugarcane requires neutral soil.

pH of rain water

The pH of rain water is approximately 7, which means that it is neutral and also represents its high purity. If the atmospheric air is polluted with oxide gases of sulphur and nitrogen, they get dissolved in the rain water and make its pH less than 7. Thus, if the pH of rain water is less than 7, then it is called acid rain. When acid rain flows into the rivers it lowers the pH of the river water also.



The survival of aquatic life in such rivers becomes difficult.

10.7 pH CALCULATION

The pH is the negative logarithm of the hydrogen ion concentration

$$pH = -\log_{10} [H^+]$$

Example: Calculate the pH of 0.01 M HNO_3?

Solution:

$[H^+] = 0.01$

$pH = -\log_{10} [H^+]$

$pH = -\log_{10} [0.01]$

$pH = -\log_{10} [1 \times 10^{-2}]$

$pH = -(\log_{10}1 - 2 \log_{10}10)$

$pH = 0 + 2 \times \log_{10}10$

$pH = 0 + 2 \times 1 = 2$

$pH = 2$

pOH: The pOH of an aqueous solution is realted to the pH.

The pOH is the negative logarithm of the hydroxyl ion concentration

$$pOH = -\log_{10}[OH^-]$$

Example: The hydroxyl ion concentration of a solution is 1×10^{-9}M. What is the pOH of the solution?

Solution

$pOH = -\log_{10} [OH^-]$

$pOH = -\log_{10} [1 \times 10^{-9}]$

$pOH = -(\log_{10} 1.0 + \log_{10} 10^{-9})$

$pOH = -(0-9 \log_{10}10)$

$pOH = -(0 - 9)$

$pOH = 9$

Relationship between pH and pOH

The pH and pOH of a water solution at 25°C are related by the following equation.

$$pH + pOH = 14$$

If either the pH or the pOH of a solution is known, the other value can be calculated.

Example: A solution has a pOH of 11.76. What is the pH of this solution?

$$pH = 14 - pOH$$

$$pH = 14 - 11.76 = 2.24$$

10.8 PROBLEMS

Example 1: Calculate the pH of 0.001 molar solution of HCl.

Solution: HCl is a strong acid and is completely dissociated in its solutions according to the process:

$$HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$$

From this process it is clear that one mole of HCl would give one mole of H^+ ions. Therefore, the concentration of H^+ ions would be equal to that of HCl, i.e., 0.001 molar or 1.0×10^{-3} mol litre^{-1}.

Thus, $[H^+] = 1 \times 10^{-3}$ mol litre^{-1}

$pH = -\log_{10}[H^+] = -\log_{10}10^{-3}$

$= -(-3 \times \log_{10}) = -(3 \times 1) = 3$

Thus, $pH = 3$

Example 2: What would be the pH of an aqueous solution of sulphuric acid which is 5×10^{-5} mol litre^{-1} in concentration.

Solution: Sulphuric acid dissociates in water as:

$$H_2SO_{4(aq)} \rightarrow 2\,H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

Each mole of sulphuric acid gives two mole of H^+ ions in the solution. One litre of H_2SO_4 solution contains 5×10^{-5} moles of H_2SO_4 which would give $2 \times 5 \times 10^{-5} = 10 \times 10^{-5}$ or 1.0×10^{-4} moles of H^+ ion in one litre of the solution.

Therefore,

$[H^+] = 1.0 \times 10^{-4}$ mol litre^{-1}

$pH = -\log_{10}[H^+] = -\log_{10}10^{-4} = -(-4 \times \log_{10}10)$

$= -(-4 \times 1) = 4$

Example 3: Calculate the pH of 1×10^{-4} molar solution of NaOH.

Solution: NaOH is a strong base and dissociates in its solution as:

$$NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$$

One mole of NaOH would give one mole of OH^- ions. Therefore,

$[OH^-] = 1 \times 10^{-4}$ mol litre^{-1}

$pOH = -\log_{10}[OH^-] = -\log_{10} \times [10^{-4}]$

$= -(-4 \times \log_{10}10) = -(-4) = 4$

Since, $pH + pOH = 14$

$pH = 14 - pOH = 14 - 4$

$= 10$

Example 4: Calculate the pH of a solution in which the concentration of the hydrogen ions is 1.0×10^{-8} mol litre^{-1}.

Solution: Here, although the solution is extremely dilute, the concentration given is not of an acid or a base but that of H^+ ions. Hence, the pH can be calculated from the relation:

$pH = -\log_{10}[H^+]$

given $[H^+] = 1.0 \times 10^{-8}$ mol litre^{-1}

$pH = -\log_{10}10^{-8} = -(-8 \times \log_{10}10)$

$= -(-8 \times 1) = 8$

Example 5: If the pH of a solution is 4.5, what is its pOH?

Solution:

$pH + pOH = 14$

$pOH = 14 - 4.5 = 9.5$

$pOH = 9.5$

Points to Remember

- A chemical change is a change in which one or more new substances are formed.
- Aerobic: Presence of oxygen.
- Anaerobic: Absence of oxygen
- Most combination reactions are exothermic
- Electrolytic decomposition reaction may occur in the presence of heat or light.
- All photo decomposition reaction are endothermic reactions.
- Double displacement reaction or metathesis may occur by the mutal exchange of ions.
- Precipitation reaction gives an insoluble salt as the product.
- Neutralisation reactions are reactions between an acid and a base that forms salt and water.
- Plants can not grow in an acidic soil.
- Neutralisation prevents tooth decay.
- Most reactions in chemistry are irreversible reactions.
- Chemical equilibrium-the rate of the forward reaction is equal to rate of the back ward reactions.
- Equilibrium is possible in a closed system.
- Temperature increases the reaction rate.
- Pressure increases the reaction rate.
- The term pH means power of hydrogen.
- pH plays a vital role in everyday life.
- In humans all bio chemical reactions take place between the pH value of 7.0 to 7.8.
- If pH of rain water is below 5.6 its called acid rain.
- Pure water is a weak electrolyte.

TEXTBOOK EVALUATION

HFPH6A

I. Choose the correct answer.

1. $H_{2(g)} + Cl_{29(g)} \rightarrow 2HCl_{(g)}$ is a
   a. Decomposition Reaction
   b. Combination Reaction
   c. Single Displacement Reaction
   d. Double Displacement Reaction

2. Photolysis is a decomposition reaction caused by ___________
   a. heat b. electricity
   c. light d. mechanical energy

3. A reaction between carbon and oxygen is represented by $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ + Heat. In which of the type(s), the above reaction can be classified?
   (i) Combination Reaction
   (ii) Combustion Reaction
   (iii) Decomposition Reaction
   (iv) Irreversible Reaction
   a. i and ii b. i and iv
   c. i, ii and iii d. i, ii and iv

4. The chemical equation
   $Na_2SO_{4(aq)} + BaCl_{2(aq)} \rightarrow BaSO_{4(s)}\downarrow + 2NaCl_{(aq)}$
   represents which of the following types of reaction?
   a. Neutralisation
   b. Combustion
   c. Precipitation
   d. Single displacement

5. Which of the following statements are correct about a chemical equilibrium?
   (i) It is dynamic in nature
   (ii) The rate of the forward and backward reactions are equal at equilibrium
   (iii) Irreversible reactions do not attain chemical equilibrium
   (iv) The concentration of reactants and products may be different
   a. i, ii and iii b. i, ii and iv
   c. ii, iii and iv d. i, iii and iv

6. A single displacement reaction is represented by $X_{(s)} + 2HCl_{(aq)} \rightarrow XCl_{2(aq)} + H_{2(g)}$. Which of the following(s) could be X.
   (i) Zn (ii) Ag (iii) Cu (iv) Mg.
   Choose the best pair.
   a. i and ii b. ii and iii
   c. iii and iv d. i and iv

7. Which of the following is not an "element + element → compound" type reaction?
   a. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$
   b. $2K_{(s)} + Br_{2(l)} \rightarrow 2KBr_{(s)}$
   c. $2CO_{(g)} + O_{2(g)} \rightarrow 2CO_{2(g)}$
   d. $4Fe_{(s)} + 3O_{2(g)} \rightarrow 2Fe_2O_{3(s)}$

8. Which of the following represents a precipitation reaction?
   a. $A_{(s)} + B_{(s)} \rightarrow C_{(s)} + D_{(s)}$
   b. $A_{(s)} + B_{(aq)} \rightarrow C_{(aq)} + D_{(l)}$
   c. $A_{(aq)} + B_{(aq)} \rightarrow C_{(s)} + D_{(aq)}$
   d. $A_{(aq)} + B_{(s)} \rightarrow C_{(aq)} + D_{(l)}$

9. The pH of a solution is 3. Its $[OH^-]$ concentration is
   a. 1×10^{-3} M
   b. 3 M
   c. 1×10^{-11} M
   d. 11 M

10. Powdered $CaCO_3$ reacts more rapidly than flaky $CaCO_3$ because of ___________.
    a. large surface area
    b. high pressure
    c. high concentration
    d. high temperature

II. Fill in the blanks

1. A reaction between an acid and a base is called _________________.
2. When lithium metal is placed in hydrochloric acid, ________ gas is evolved.

3. The equilibrium attained during the melting of ice is known as ____________.
4. The pH of a fruit juice is 5.6. If you add slaked lime to this juice, its pH ______________ (increse/decrese)
5. The value of ionic product of water at 25^0 C is ______________.
6. The normal pH of human blood is __________
7. Electrolysis is type of ________________ reaction
8. The number of products formed in a synthesis reaction is __________
9. Chemical volcano is an example for ________________ type of reaction
10. The ion formed by dissolution of H^+ in water is called ________________

III. Match the following

1. Identify the types of reaction

REACTION	TYPE
$NH_4OH_{(aq)} + CH_3COOH_{(aq)} \rightarrow CH_3COONH_{4(aq)} + H_2O_{(l)}$	Single Displacement
$Zn_{(s)} + CuSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Cu_{(s)}$	Combustion
$ZnCO_{3(s)} + \xrightarrow{Heat} ZnO_{(s)} + CO_{2(g)}$	Neutralisation
$C_2H_{4(g)} + 4O_{2(g)} \rightarrow 2CO_{2(g)} + 2H_2O_{(g)} + Heat$	Thermal decomposition

IV. True or False: (If false give the correct statement)

1. Silver metal can displace hydrogen gas from nitric acid.
2. The pH of rain water containing dissolved gases like SO_3, CO_2, NO_2 will be less than 7.
3. At the equilibrium of a reversible reaction, the concentration of the reactants and the products will be equal.
4. Periodical removal of one of the products of a reversible reaction increases the yield.
5. On dipping a pH paper in a solution, it turns into yellow. Then the solution is basic.

V. Short answer questions:

1. When an aqueous solution of potassium chloride is added to an aqueous solution of silver nitrate, a white precipitate is formed. Give the chemical equation of this reaction.
2. Why does the reaction rate of a reaction increase on raising the temperature?
3. Define combination reaction. Give one example for an exothermic combination reaction.
4. Differentiate reversible and irreversible reactions

VI. Answer in detail

1. What are called thermolysis reactions?
2. Explain the types of double displacement reactions with examples.
3. Explain the factors influencing the rate of a reaction
4. How does pH play an important role in everyday life?
5. What is a chemical equilibrium? What are its characteristics?

VII. HOT questions

1. A solid compound 'A' decomposes on heating into 'B' and a gas 'C'. On passing the gas 'C' through water, it becomes acidic. Identify A, B and C.

2. Can a nickel spatula be used to stir copper sulphate solution? Justify your answer.

VIII. Solve the following problems

1. Lemon juice has a pH 2, what is the concentration of H^+ ions?
2. Calculate the pH of 1.0×10^{-4} molar solution of HNO_3.
3. What is the pH of 1.0×10^{-5} molar solution of KOH?
4. The hydroxide ion concentration of a solution is 1×10^{-11}M. What is the pH of the solution?

REFERENCE BOOKS

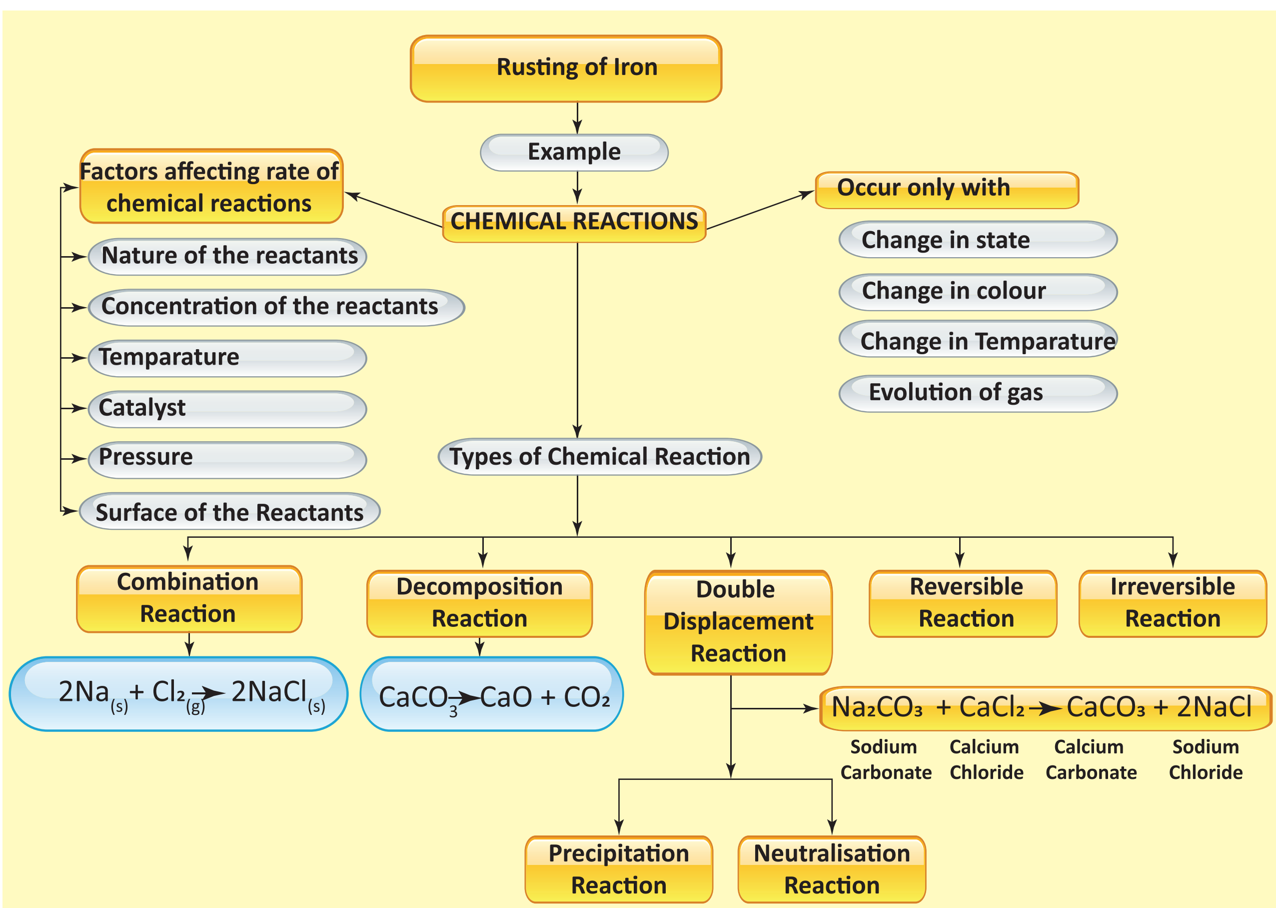
1. Text book of inorganic chemistry-P.L.Soni-S.Chand & sons publishers, New Delhi.
2. Principles of Physical Chemistry- B.R.Ruri, L.R. Sharma, Vishal publishing Co Punjab.

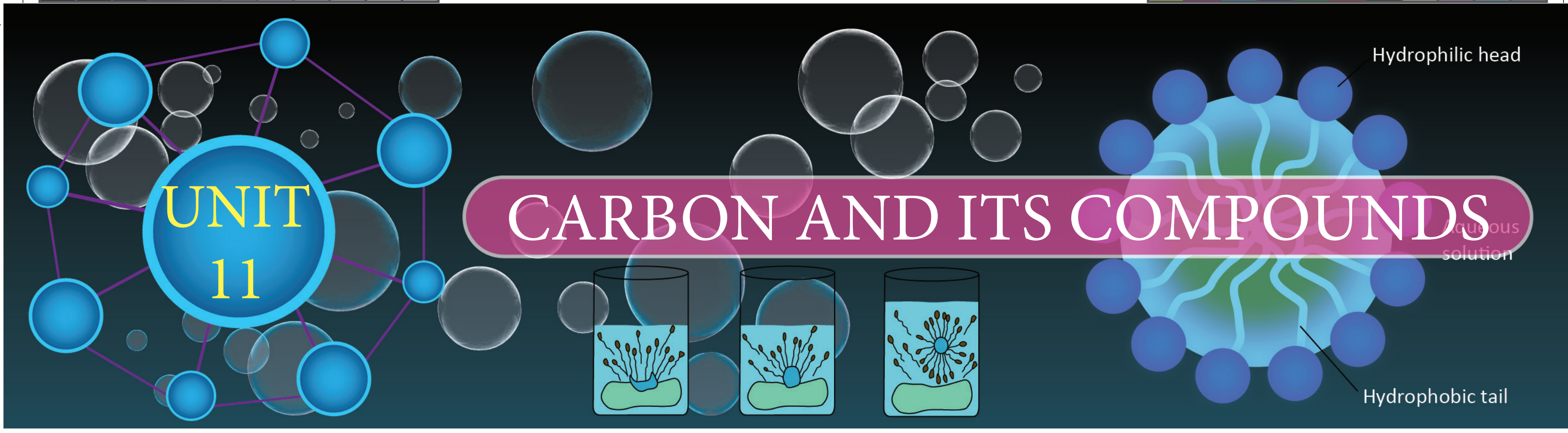
INTERNET RESOURCES

Webliography:www.chem4kids.com

http://aravindguptatoys.com/filims.html

Concept Map





UNIT 11

CARBON AND ITS COMPOUNDS

HV8C7L

Learning Objectives

After studying this lesson, the student will be able to:

- know the importance of organic compounds.
- classify the organic compounds and name them based on IUPAC rules.
- identify the functional groups of organic compounds.
- explain the preparation, properties and uses of ethanol and ethanoic acids.
- know the composition and preparation of soap and detergent.
- understand the cleansing action of soap and detergents.
- differentiate soap and detergents.

INTRODUCTION

You have studied, in your lower classes, that carbon is an inseparable element in human life as we use innumerable number of carbon compounds in our day to day life. Because, the food we eat, medicines we take when ill, clothes we wear; domestic and automobile fuels, paint, cosmetics, automobile parts, etc., that we use contain carbon compounds. The number of carbon compounds found in nature and man-made, is much higher than that of any other element in the periodic table. Infact there are more than 5 million compounds of carbon. The unique nature of carbon, such as catenation, tetravalency and multiple bonding, enables it to combine with itself or other elements like hydrogen, oxygen, nitrogen,sulphur etc., and hence form large number of compounds. All these compounds are made of covalent bonds. These compounds are called **organic compounds.** In this lesson, you will learn about carbon compounds.

11.1 GENERAL CHARACTERISTICS OF ORGANIC COMPOUNDS

Everything in this world has unique character, similarly organic compounds are unique in their characteristics. Some of them are given below:

- Organic compounds have a high molecular weight and a complex structure.
- They are mostly insoluble in water, but soluble in organic solvents such as ether, carbon tetrachloride, toluene, etc.
- They are highly inflammable in nature
- Organic compounds are less reactive compared to inorganic compounds. Hence, the reactions involving organic compounds proceed at slower rates.

- Mostly organic compounds form covalent bonds in nature.
- They have lower melting point and boiling point when compared to inorganic compounds
- They exhibit the phenomenon of isomerism, in which a single molecular formula represents several organic compounds that differ in their physical and chemical properties
- They are volatile in nature.
- Organic compounds can be prepared in the laboratory

11.2 CLASSIFICATION OF ORGANIC COMPOUNDS BASED ON THE PATTERN OF CARBON CHAIN

What is the significance of classification? There are millions of organic compounds known and many new organic compounds are discovered every year in nature or synthesized in laboratory. This may mystify organic chemistry to a large extent. However, a unique molecular structure can be assigned to each compound and it can be listed by using systematic methods of classification and eventually named on the basis of its structural arrangements. In early days, chemists recognised that compounds having similar structural features have identical chemical properties. So they began to classify compounds based on the common structural arrangements found among them.

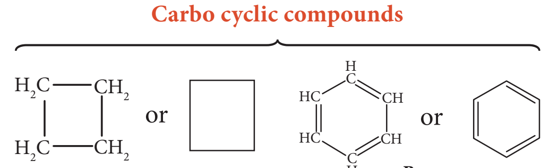
Organic chemistry is the chemistry of catenated carbon compounds. The carbon atoms present in organic compounds are linked with each other through covalent bonds and thus exist as chains. By this way, organic compounds are classified into two types as follows:

1. Acyclic or Open chain compounds: These are the compounds in which the carbon atoms are linked in a linear pattern to form the chain. If all the carbon atoms in the chain are connected by single bonds, the compound is called as **saturated.** If one or more double bonds or triple bonds exist between the carbon atoms, then the compound is said to **unsaturated**.

CH_3-CH_2-CH_3	CH_3-CH=CH_2
Propane	Propene
Saturated compound	Unsaturated compound

2. Cyclic Compounds: Organic compounds in which the chain of carbon atoms is closed or cyclic are called **cyclic compounds.** If the chain contains only carbon atoms, such compounds are called **carbocyclic compounds.** If the chain contains carbon and other atoms like oxygen, nitrogen, sulphur, etc., these compounds are called **heterocyclic compounds.** Carbocyclic compounds are further subdivided into **alicyclic** and **aromatic compounds.** Alicyclic compounds contain one or more carbocyclic rings which may be saturated or unsaturated whereas aromatic compounds contain one or more benzene rings (ring containing alternate double bonds between carbon atoms). E.g.

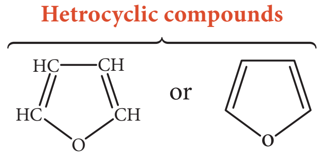
Carbo cyclic compounds



Cyclobutane
Alicyclic Compound

Benzene
Aromatic Compound

Hetrocyclic compounds



Furan

Figure 11.1 depicts the classification of organic compounds based on the pattern of carbon arrangements and their bonding in organic compounds:

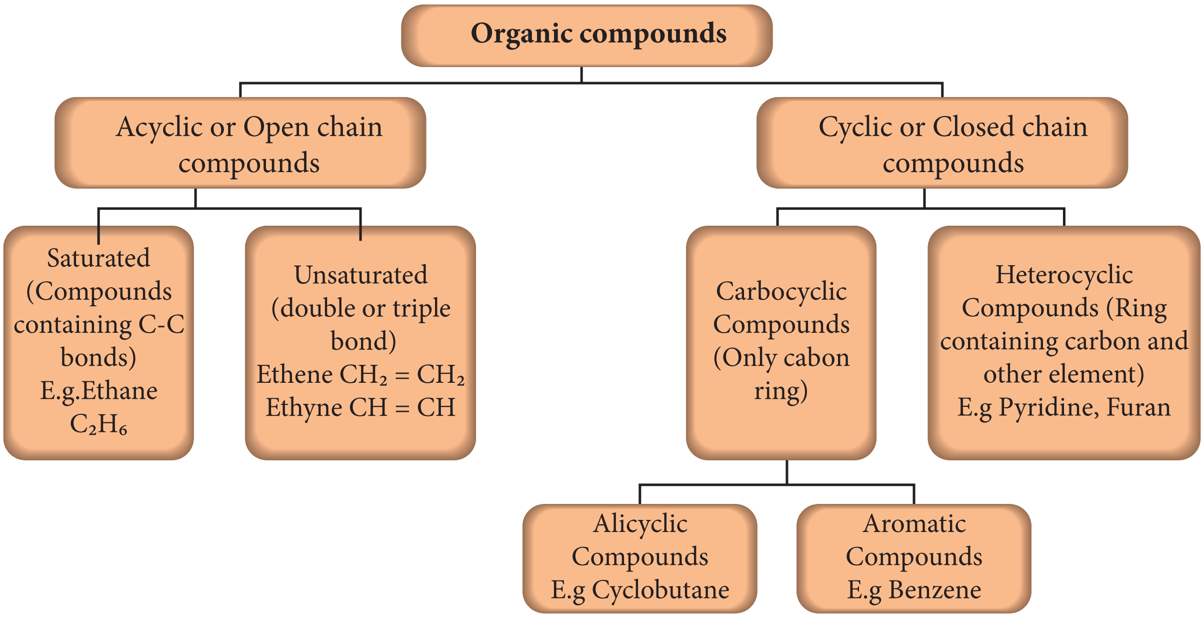


Figure 11.1 Classification of organic compounds

11.3 CLASSES OF ORGANIC COMPOUNDS (BASED ON THE KIND OF ATOMS)

Other than carbon, organic compounds contain atoms like hydrogen, oxygen, nitrogen, etc., bonded to the carbon. Combination of these kinds of atoms with carbon gives different classes of organic compounds. In the following section, let us discuss various classes of organic compounds.

11.3.1 Hydrocarbons

The organic compounds that are composed of only carbon and hydrogen atoms are called **hydrocarbons.** The carbon atoms join together to form the framework of the compounds. These are regarded as the parent organic compounds and all other compounds are considered to be derived from hydrocarbons by replacing one or more hydrogen atoms with other atoms or group of atoms. Hydrocarbons are, further, sub divided into three classes such as:

(a) Alkanes: These are hydrocarbons, which contain only single bonds. They are represented by the general formula $\mathbf{C_nH_{2n+2}}$ (where n = 1,2, 3, ……). The simplest alkane (for n=1) is methane (CH_4). Since, all are single bonds in alkanes, they are saturated compounds.

(b) Alkenes: The hydrocarbons, which contain one or more C=C bonds are called alkenes. These are unsaturated compounds. They are represented by the general formula $\mathbf{C_nH_{2n}}$. The simplest alkene contains two carbon atoms (n=2) and is called ethylene (C_2H_4).

(c) Alkynes: The hydrocarbons containing carbon to carbon triple bond are called **alkynes.** They are also unsaturated as they contain triple bond between carbon atoms. They have the general formula $\mathbf{C_nH_{2n-2}}$. Acetylene (C_2H_2) is the simplest alkyne, which contains two carbon atoms. Table 11.1 lists the first five hydrocarbons of each class:

Table 11.1 Hydrocarbons containing 1to 5 carbon atoms

No. of carbon atoms	Alkane (C_nH_{2n+2})	Alkene (C_nH_{2n})	Alkyne (C_nH_{2n-2})
1	Methane (CH_4)	-	-
2	Ethane (C_2H_6)	Ethene (C_2H_4)	Ethyne (C_2H_2)
3	Propane (C_3H_8)	Propene (C_3H_6)	Propyne (C_3H_4)
4	Butane (C_4H_{10})	Butene (C_4H_8)	Butyne (C_4H_6)
5	Pentane (C_5H_{12})	Pentene (C_5H_{10})	Pentyne (C_5H_8)

11.3.2 Characteristics of hydrocarbons:

- Lower hydrocarbons are gases at room temperature E.g. methane, ethane are gases.
- They are colourless and odourless.
- The boiling point of hydrocarbons increases with an increase in the number of carbon atoms.
- They undergo combustion reaction with oxygen to form CO_2 and water.
- Alkanes are least reactive when compared to other classes of hydrocarbons.
- Alkynes are the most reactive due to the presence of the triple bond.
- Alkanes are saturated whereas alkenes and alkynes are unsaturated.
- They are insoluble in water.

Test to identify saturated and unsaturated compounds:

- Take the given sample solution in a test tube.
- Add a few drops of bromine water and observe any characteristic change in colour.
- If the given compound is unsaturated, it will decolourise bromine water.
- Saturated compounds do not decolourise bromine.

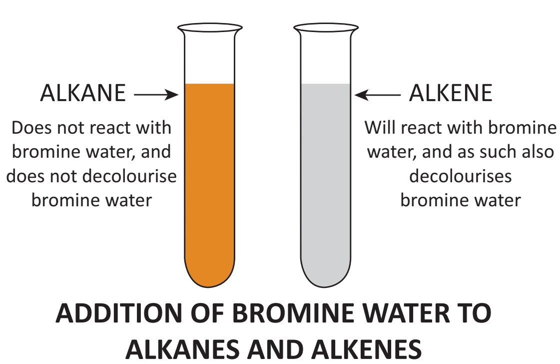


Figure 11.2 Test to identify unsaturated compounds

11.3.3 Classification of organic compounds based on functional groups

The structural frameworks of organic compounds are made of carbon and hydrogen, which are relatively less reactive. But, the presence of some other atoms or group of atoms makes the compounds more reactive and thus determines the chemical properties of the compound. These groups are called **functional groups.**

A functional group is an atom or group of atoms in a molecule, which gives its characteristic chemical properties.

The chemical properties of an organic compound depend on its functional group whereas its physical properties rely on remaining part of the structure. Carbon to carbon multiple bonds (C=C, C≡C) also are considered as functional groups as many of the properties are influenced by these bonds. Other functional groups include atoms of halogens, –OH, –CHO, –COOH, etc.

For example, ethane is a hydrocarbon having molecular formula C_2H_6. If one of its hydrogen is replaced by –OH group, you will get an alcohol. Leaving the functional group, the rest of the structure is represented by '**R**'. Thus an alcohol is represented by 'R-OH'

CH_3-CH_3	CH_3-CH_2-OH → Functional Group
Ethane	Ethanol
Hydrocarbon	Alcohol

A series of compounds containing the same functional group is called a **class of organic compounds.** Table 11.2 shows various classes or families of organic compounds and their functional groups:

Table 11.2 **Classes of organic compounds based on functional group**

Class of the compound	Functional group	Common Formula	Examples
Alcohols	–OH	R-OH	Ethanol, CH_3CH_2OH
Aldehydes	$-\overset{\overset{\large O}{\|}}{C}-H$	R-CHO	Acetaldehyde, CH_3CHO
Ketones	$-\overset{\overset{\large O}{\|}}{C}-$	R–CO-R	Acetone, CH_3COCH_3
Carboxylic acids	$-\overset{\overset{\large O}{\|}}{C}-OH$	R-COOH	Acetic acid, CH_3COOH
Ester	$-\overset{\overset{\large O}{\|}}{C}-OR$	R-COOR	Methyl acetate, CH_3COOCH_3
Ether	–O–R	R-O-R	Dimethyl ether, CH_3OCH_3

11.4 HOMOLOGOUS SERIES

Homologous series is a group or a class of organic compounds having same general formula and similar chemical properties in which the successive members differ by a -CH_2 group.

Let us consider members of alkanes given in Table 11.1. Their condensed structural formulas are given below:

Methane	-	CH_4
Ethane	-	CH_3CH_3
Propane	-	$CH_3CH_2CH_3$
Butane	-	$CH_3(CH_2)_2CH_3$
Pentane	-	$CH_3(CH_2)_3CH_3$

If you observe the above series. you can notice that each successive member has one methylene group more than the precedent member of the series and hence they are called homologs.

11.4.1 Characteristics of homologous series

- Each member of the series differs from the preceding or succeeding member by one methylene group ($-CH_2$) and hence by a molecular mass of 14 amu.
- All members of a homologous series contain the same elements and functional group.
- They are represented by a general molecular formula. e.g. Alkanes, C_nH_{2n+2}.
- The members in each homologous series show a regular gradation in their physical properties with respect to their increase in molecular mass.
- Chemical properties of the members of a homologous series are similar.
- All the members can be prepared by a common method.

11.5 NOMENCLATURE OF ORGANIC COMPOUNDS

11.5.1 Why do we need nomenclature?

In ancient days, the names of organic compounds were related to the natural things from which they were obtained. For example, the formic acid was initially obtained by distillation of 'red ants'. Latin name of the red ant is 'Formica'. So, the name of the formic acid was derived from the Latin name of its source Later, the organic compounds were synthesized from sources other than the natural sources. So scientists framed a systematic method for naming the organic compounds based on their structures. Hence, a set of rules was formulated by IUPAC (**International Union of Pure and Applied Chemistry**) for the nomenclature of chemical compounds.

11.5.2 Components of an IUPAC name

The IUPAC name of the any organic compound consists of three parts:

i. Root word
ii. Prefix
iii. Suffix

These parts are combined as per the following sequence to get the IUPAC name of the compound:

Prefix + Root Word + Suffix → IUPAC Name

(i) Root word: It is the basic unit, which describes the carbon skeleton. It gives the number of carbon atoms present in the parent chain of the compound and the pattern of their arrangement. Based on the number of carbon atoms present in the carbon skeleton, most of the names are derived from Greek numerals (except the first four). Table 11.3 shows the root words for the parent chain of hydrocarbons containing 1to10 carbon atoms:

Table 11.3 Root words of hydrocarbons

No. of carbon atoms	Root word
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-
6	Hex-
7	Hept-
8	Oct-
9	Non-
10	Dec-

(ii) Prefix: The prefix represents the substituents or branch present in the parent chain. Atoms or group of atoms, other than hydrogen, attached to carbon of the parent chain are called substituents. Table 11.4 presents the major substituents of organic compounds and respective prefix used for them:

Table 11.4 Prefix for IUPAC Name

Substituent	Prefix used
-F	Fluoro
-Cl	Chloro
-Br	Bromo
-I	Iodo
$-NH_2$	Amino
$-CH_3$	Methyl
$-CH_2CH_3$	Ethyl

(iii) Suffix

The suffix forms the end of the name. It is divided into two parts such as **(a) Primary suffix** and **(b) Secondary suffix.** The primary suffix comes after the root word. **It represents the nature in carbon to carbon bonding of the parent chain**. If all the bonds between the carbon atoms of the parent chain are single, then suffix **'ane'** has to be used. Suffix **'ene'** and **'yne'** are used for the compounds containing double and triple bonds respectively. **The secondary suffix describes the functional group of the compound**.

Table 11.5 Suffix for IUPAC Name

Class of the Compound	Functional group	Suffix used
Alcohols	–OH	-ol
Aldehydes	–CHO	-al
Ketones	O ‖ –C–	-one
Carboxylic acids	–COOH	-oic acid

11.5.3 IUPAC rules for naming organic compounds:

- **Rule1:** Identify the longest chain of carbon atoms to get the parent name (root word).
- **Rule 2:** Number the carbon atoms of the parent chain, **beginning at the closest end of the substituent or functional group**. These are called **locant numbers**. *If both functional group and substituent are present, then the priority will be given to the functional group*.
- **Rule 3:** In case of alkenes and alkynes, locate the double bond or triple bond and use its locant number followed by a dash and a primary suffix. The carbon chain is numbered in such a way that the multiple bonds have the lowest possible locant number.
- **Rule 4:** If the compound contains functional group, locate it and use its locant number followed by a dash and a secondary suffix.
- **Rule 5:** When the primary and secondary suffixes are joined, the terminal 'e' of the primary suffix is removed.
- **Rule 6:** Identify the substituent and use a number followed by a dash and a prefix to specify its location and identity.

11.5.4 IUPAC Nomenclature of hydrocarbons – Solved examples

Let us try to name, systematically, some of the linear and substituted hydrocarbons by following IUPAC rules:

Example 1: CH_3-CH_2-CH_2-CH_2-CH_3

Step 1: It is a five- carbon chain and hence the root word is 'Pent'. (Rule 1)

Step 2: All the bonds between carbon atoms are single bonds, and thus the suffix is 'ane'.

So, its name is **Pent + ane = Pentane**

Example 2:

$$\begin{array}{l} \quad\quad\;\; CH_3 \\ \quad\quad\;\;\; | \\ CH_3–CH–CH_2–CH_2–CH_3 \end{array}$$

Step 1: The longest chain contains five carbon atoms and hence the root word is 'Pent'.

Step 2: There is a substituent. So, the carbon chain is numbered from the left end, which is closest to the substituent. (Rule 2)

$$\begin{array}{l} \quad\quad\;\; CH_3 \\ \;^{1}\quad\;\; |^{2} \quad\; ^{3} \quad\quad ^{4} \quad\quad ^{5} \\ CH_3–CH–CH_2–CH_2–CH_3 \\ \longrightarrow \end{array}$$

Step 2: All are single bonds between the carbon atoms and thus the suffix is 'ane'.

Step 3: The substituent is a methyl group and it is located at second carbon atom. So, its locant number is 2. Thus the prefix is '2-Methyl'. (Rule 6).

The name of the compound is

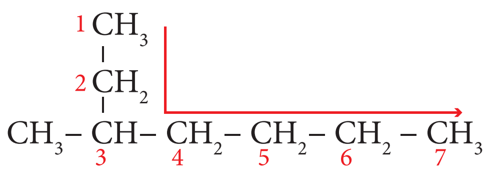
2-Methyl + pent +ane = 2-Methylpentane

Example 3:

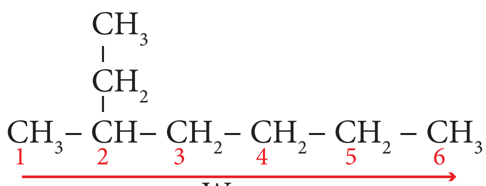
$$\begin{array}{l} \quad\quad\;\; CH_3 \\ \quad\quad\;\;\; | \\ \quad\quad\;\; CH_2 \\ \quad\quad\;\;\; | \\ CH_3– CH– CH_2– CH_2– CH_2 – CH_3 \end{array}$$

Step 1: The longest chain contains seven carbon atoms and hence the root word is 'Hept'.

Step 2: There is a substituent. So, the carbon chain is numbered from the end, which is closest to substituent. (Rule 2)



Correct



Wrong

Step 2: All are single bonds between the carbon atoms and thus the suffix is 'ane'.

Step 3: The substituent is a methyl group and it is located at third carbon. So, its locant number is 3. Thus the prefix is '3-Methyl'. (Rule 6)

Hence the name of the compound is **3-Methyl + hept + ane = 3 –Methylheptane**

Example 4: CH_3-CH_2-CH_2-CH=CH_2

Step 1: It is a 'five- carbon atoms chain' and hence the root word is 'Pent'. (Rule 1)

Step 2: There is a carbon to carbon double bond. The suffix is 'ene'.

Step 3: The carbon chain is numbered from the end such that double bond has the lowest locant number as shown below: (Rule 3):

$$\overset{5}{CH_3}-\overset{4}{CH_2}-\overset{3}{CH_2}-\overset{2}{CH}=\overset{1}{CH_2}$$

Step 4: The locant number of the double bond is 1 and thus the suffix is '-1-ene'.

So, the name of the compound is **Pent + (-1-ene) = Pent-1-ene**

11.5.5 IUPAC Nomenclature of other classes – Solved examples

Example 1: CH_3-CH_2-CH_2-OH

Step1: The parent chain consists of 3 carbon atoms. The root word is 'Prop'.

Step 2: There are single bonds between the carbon atoms of the chain. So, the **primary suffix** is 'ane'.

Step 3: Since, the compound contains –OH group, it is an alcohol. The carbon chain is numbered from the end which is closest to –OH group. (Rule 3)

$$\overset{3}{CH_3}-\overset{2}{CH_2}-\overset{1}{CH_2}-OH$$

Step 4: The locant number of –OH group is 1 and thus the secondary suffix is '1-ol'.

The name of the compound is **Prop + ane + (1-ol) = Propan-1-ol**

Note: Terminal 'e' of 'ane' is removed as per Rule 5

Example 2: CH_3COOH

Step1: The parent chain consists of 2 carbon atoms. The root word is 'Eth'.

Step 2: All are single bonds between the carbon atoms of the chain. So the primary suffix is 'ane'.

Step 3: Since the compound contains the–COOH group, it is a carboxylic acid. The secondary suffix is 'oic acid'

The name of the compound is **Eth + ane + oic acid) = Ethanoic acid**

Table 11.6 lists IUPAC names homologs of various classes of organic compounds

Test yourself:

Obtain the IUPAC name of the following compounds systematically:

(a) CH_3CHO

(b) $CH_3CH_3COCH_3$

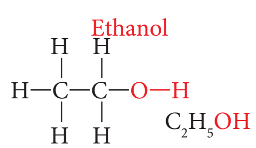
(c) $ClCH_2$-CH_2-CH_2-CH_3

Table 11.6 IUPAC Name of various classes of compounds

No. of carbons atoms	IUPAC Name			
	Alcohols	Aldehydes	Ketones	Carboxylic acid
1	Methanol (CH_3OH)	Methanal ($HCHO$)	-	Methanoic acid ($HCOOH$)
2	Ethanol (CH_3CH_2OH)	Ethanal (CH_3CHO)	-	Ethanoic acid (CH_3COOH)
3	Propanol ($CH_3CH_2CH_2OH$)	Propanal (CH_3CH_2CHO)	Propanone (CH_3COCH_3)	Propanoic acid (CH_3CH_2COOH)
4	Butanol ($CH_3CH_2CH_2CH_2OH$)	Butanal ($CH_3CH_2CH_2CHO$)	Butanone ($CH_3COCH_2CH_3$)	Butanoic acid ($CH_3CH_2CH_2COOH$)
5	Pentanol ($CH_3CH_2CH_2CH_2CH_2OH$)	Pentanal ($CH_3CH_2CH_2CH_2CHO$)	Pentanone ($CH_3COCH_2CH_2CH_3$)	Pentanoic acid ($CH_3CH_2CH_2CH_2COOH$)

11.6 ETHANOL (CH_3CH_2OH)

Ethanol is commonly known as alcohol. All alcoholic beverages and some cough syrups contain ethanol. Its molecular formula is C_2H_5OH. Its structural formula is



11.6.1 Manufacture of ethanol

Ethanol is manufactured in industries by the fermentation of molasses, which is a by-product obtained during the manufacture of sugar from sugarcane. Molasses is a dark coloured syrupy liquid left after the crystallization of sugar from the concentrated sugarcane juice. Molasses contain about 30% of sucrose, which cannot be separated by crystallization. It is converted into ethanol by the following steps:

(i) Dilution of molasses

Molasses is first diluted with water to bring down the concentration of sugar to about 8 to 10 percent.

(ii) Addition of Nitrogen source

Molasses usually contains enough nitrogenous matter to act as food for yeast during the fermentation process. If the nitrogen content of the molasses is poor, it may be fortified by the addition of **ammonium sulphate** or **ammonium phosphate**.

(iii) Addition of Yeast

The solution obtained in step (ii) is collected in large 'fermentation tanks' and yeast is added to it. The mixture is kept at about 303K for a few days. During this period, the enzymes invertase and zymase present in yeast, bring about the conversion of sucrose into ethanol.

$$\underset{\text{Sugar}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{invertase}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{fructose}}{C_6H_{12}O_6}$$

$$\underset{\text{glucose or fructose}}{C_6H_{12}O_6} \xrightarrow{\text{zymase}} \underset{\text{ethanol}}{2C_2H_5OH} + 2\,CO_2$$

The fermented liquid is technically called **wash**.

(iv) Distillation of 'Wash'

The fermented liquid (i.e. wash), containing 15 to 18 percent alcohol, is now subjected to fractional distillation. The main fraction drawn is an aqueous solution of ethanol which contains

95.5% of ethanol and 4.5% of water. This is called **rectified spirit**. This mixture is then refluxed over quicklime for about 5 to 6 hours and then allowed to stand for 12 hours. On distillation of this mixture, pure alcohol (100%) is obtained. This is called **absolute alcohol**.

More to know

Yeast and Fermentation: Yeasts are single–celled microorganisms, belonging to the class of fungi. The enzymes present in yeasts catalyse many complex organic reactions. Fermentation is conversion of complex organic molecules into simpler molecules by the action of enzymes. E.g. Curdling of milk

11.6.2 Physical properties

i) Ethanol is a colourless liquid, having a pleasant smell and a burning taste.

ii) It is a volatile liquid. Its boiling point is 78° C (351K), which is much higher than that of its corresponding alkane, i.e. ethane (Boiling Point = 184 K).

iii) It is completely miscible with water in all proportions.

11.6.3 Chemical Properties

(i) Dehydration (Loss of water)

When ethanol is heated with con H_2SO_4 at 443K, it loses a water molecule i.e. dehydrated to form ethene.

$$\underset{\text{Ethanol}}{CH_3CH_2OH} \xrightarrow[443K]{Conc.H_2SO_4} \underset{\text{Ethene}}{CH_2 = CH_2} + H_2O$$

(ii) Reaction with sodium:

Ethanol reacts with sodium metal to form sodium ethoxide and hydrogen gas.

$$2C_2H_5OH + 2Na \longrightarrow \underset{\text{sodium ethoxide}}{2C_2H_5ONa} + H_2 \uparrow$$

(iii) Oxidation:

Ethanol is oxidized to ethanoic acid with alkaline $KMnO_4$ or acidified $K_2Cr_2O_7$

$$CH_3CH_2OH \xrightarrow[2[O]]{K_2Cr_2O_7 / H^+} \underset{\text{Ethanoic acid}}{CH_3COOH} + H_2O$$

During this reaction, the orange colour of $K_2Cr_2O_7$ changes to green. Therefore, this reaction can be used for the identification of alcohols.

(iv) Esterification:

The reaction of an alcohol with a carboxylic acid gives a compound having fruity odour. This compound is called an **ester** and the reaction is called esterification. Ethanol reacts with ethanoic acid in the presence of conc. H_2SO_4 to form ethyl ethanoate, an ester.

$$\underset{\text{Ethanol}}{C_2H_5OH} + \underset{\text{Ethanoic acid}}{CH_3COOH} \xrightarrow{conc.H_2SO_4} \underset{\text{Ethyl ethanoate}}{CH_3COOC_2H_5} + H_2O$$

(v) Dehydrogenation:

When the vapour of ethanol is passed over heated copper, used as a catalyst at 573 K, it is dehydrogenated to acetaldehyde.

$$\underset{\text{Ethanol}}{CH_3CH_2OH} \xrightarrow[573K]{Cu} \underset{\text{Acetadehyde}}{CH_3CHO} + H_2\uparrow$$

(vi) Combustion:

Ethanol is highly inflammable liquid. It burns with oxygen to form carbon dioxide and water.

$$\underset{\text{Ethanol}}{C_2H_5OH} + 3O_2 \longrightarrow \underset{\text{Carbon dioxide}}{2CO_2} + 3H_2O$$

11.6.4 Uses of ethanol

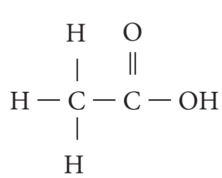
Ethanol is used

- in medical wipes, as an antiseptic.
- as an anti-freeze in automobile radiators.
- for effectively killing micro organisms like bacteria, fungi, etc., by including it in many hand sanitizers.

- as an antiseptic to sterilize wounds in hospitals.
- as a solvent for drugs, oils, fats, perfumes, dyes, etc.
- in the preparation of **methylated spirit** (mixture of 95% of ethanol and 5% of methanol) **rectified spirit** (mixture of 95.5% of ethanol and 4.5% of water), power alcohol (mixture of petrol and ethanol) and denatured spirit (ethanol mixed with pyridine).
- to enhance the flavour of food extracts, for example vanilla extract; a common food flavour, which is made by processing vanilla beans in a solution of ethanol and water.

11.7 ETHANOIC ACID (CH_3COOH)

Ethanoic acid or acetic acid is one of the most important members of the carboxylic acid family. Its molecular formula is $C_2H_4O_2$. Its structural formula is



11.7.1 Manufacture of ethanoic acid

Ethanoic acid is prepared in large scale, by the oxidation of ethanol in the presence of alkaline potassium permanganate or acidified potassium dichromate.

$$\underset{\text{Ethanol}}{CH_3CH_2OH} \xrightarrow[2[O]]{KMnO_4/\,OH^-} \underset{\text{Ethanoic acid}}{CH_3COOH} + H_2O$$

11.7.2 Physical Properties

(i) Ethanoic acid is a colourless liquid having an unpleasant odour.

(ii) It is sour in taste.

(iii) It is miscible with water in all proportions.

(iv) Its boiling point is higher than the corresponding alcohols, aldehydes and ketones.

(v) On cooling, pure ethanoic acid is frozen to form ice like flakes. They look like glaciers, so it is called **glacial acetic acid.**

11.7.3 Chemical Properties

(i) **Reaction with metal:** Ethanoic acid reacts with active metals like Na, Zn, etc., to liberate hydrogen and form sodium ethanoate.

$$2CH_3COOH + Zn \rightarrow (CH_3COO)_2\,Zn + H_2\uparrow$$

$$2CH_3COOH + 2Na \rightarrow 2CH_3COONa + H_2\uparrow$$

(ii) **Reaction with carbonates and bicarbonates:** Ethanoic acid reacts with sodium carbonate and sodium bicarbonate, which are weaker bases and liberates CO_2, with brisk effervescence.

$$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + CO_2\uparrow + H_2O$$

$$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + CO_2\uparrow + H_2O$$

(iii) **Reaction with base:** Ethanoic acid reacts with sodium hydroxide to form sodium ethanoate and water.

$$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$$

(iv) **Decarboxylation (Removal of CO_2):**

When a sodium salt of ethanoic acid is heated with soda lime (solid mixure of 3 parts of NaOH and 1 part of CaO), methane gas is formed.

$$CH_3COONa \xrightarrow{NaOH\,/\,CaO} CH_4\uparrow + Na_2CO_3$$

11.7.4 Uses of ethanoic acid

Acetic acid, in lower concentration, is used as a food additive, a flavoring agent and a preservative.

Ethanoic acid is used

- in the manufacture of plastic.
- in making dyes, pigments and paint.
- in printing on fabrics.
- as a laboratory reagent.
- for coagulating rubber from latex.
- in the production of pharmaceuticals.

11.8 ORGANIC COMPOUNDS IN DAILY LIFE

Organic compounds are inseparable in human life. They are used by mankind or associated at all stages of life right from one's birth to death. Various classes of organic compounds and their uses in our daily life as follows:

Hydrocarbons

- Fuels like LPG, Petrol, Kerosene.
- Raw materials for various important synthetic materials.
- Polymeric materials like tyre, plastic containers.

Alcohols

- As a solvent and an antiseptic agent.
- Raw materials for various important synthetic materials.

Aldehydes

- Formaldehyde as a disinfectant.
- Raw materials for synthetic materials.

Ketones

- As a solvent.
- Stain Remover.

Ethers

- Anaesthetic agents.
- Pain Killer.

Esters

- All the cooking oils and lipids contain esters.

11.9 SOAPS AND DETERGENTS

Soaps and the Detergents are materials that are used by us for cleaning purposes because pure water alone cannot remove all types of dirt or any oily substance from our body or clothes. They contain 'surfactants', which are compounds with molecules that line up around water to break the 'surface tension'. Both of them having a different chemical nature. ***Soap*** is a cleaning agent that is composed of one or more salts of fatty acids. ***Detergent*** is a chemical compound or a mixture of chemical compounds, which is used as a cleaning agent, also. They perform their cleaning actions in certain specific conditions. You will learn more about this in detail, in the following units.

11.9.1 Soap

Soaps are sodium or potassium salts of some long chain carboxylic acids, called fatty acids. Soap requires two major raw materials: i) fat and ii) alkali. The alkali, most commonly used in the preparation of soap is sodium hydroxide. Potassium hydroxide can also be used. A potassium-based soap creates a more water-soluble product than a sodium-based soap. Based on these features, there are two types of soaps:

A. HARD SOAP

Soaps, which are prepared by the ***saponification of oils or fats with caustic soda*** (sodium hydroxide), are known as hard soaps. They are usually used for washing purposes.

B. SOFT SOAP

Soaps, which are prepared by the ***saponification of oils or fats with potassium salts***, are known as soft soaps. They are used for cleansing the body.

Manufacture of soap

KETTLE PROCESS:

This is the oldest method. But, it is still widely used in the small scale preparation of soap. There are mainly, two steps to be followed in this process.

i) Saponification of oil:

The oil, which is used in this process, is taken in an iron tank (kettle). The alkaline solution (10%) is added into the kettle, a little in excess. The mixture is boiled by passing steam through it. The oil gets hydrolysed after several hours of boiling. This process is called Saponification

ii) Salting out of soap:

Common salt is then added to the boiling mixture. Soap is finally precipitated in the tank. After several hours the soap rises to the top of the liquid as a 'curdy mass'. The neat soap is taken off from the top. It is then allowed to cool down.

Effect of hard water on soap

Hard water contains calcium and magnesium ions (Ca^{2+} and Mg^{2+}) that limit the cleaning action of soap. When combined with soap, hard water develops a thin layer (precipitates of the metal ions) called 'scum', which leaves a deposit on the clothes or skin and does not easily rinse away. Over time, this can lead to the deterioration of the fabric and eventually ruin the clothes. On the other hand, detergents are made with chemicals that are not affected by hard water.

DO YOU KNOW?

Why ordinary soap is not suitable for using with hard water?

Ordinary soaps when treated with hard water, precipitate as salts of calcium and magnesium. **They appear at the surface of the cloth as sticky grey scum.** Thus, the soaps cannot be used conveniently in hard water.

11.9.2 Detergents

Development of synthetic detergents is a big achievement in the field of cleansing. These soaps possess the desirable properties of ordinary soaps and also can be used with hard water and in acidic solutions. These are salts of sulphonic acids or alkyl hydrogen sulphates in comparison to soap, which are salts of carboxylic acids. The detergents do not form precipitates with Ca^{2+} and Mg^{2+} present in hard water. So, the cleansing action of detergents is better than that of soaps.

Preparation of detergents

Detergents are prepared by adding sulphuric acid to the processed hydrocarbon obtained from petroleum. This chemical reaction result in the formation of molecules similar to the fatty acid in soap. Then, an alkali is added to the mixture to produce the 'surfactant molecules', which do not bond with the minerals present in the hard water, thus preventing the formation of their precipitates.

In addition to a 'surfactant', the modern detergent contains several other ingredients. They are listed as follows:

i) Sodium silicate, which prevents the corrosion and ensures that the detergent does not damage the washing machine.

ii) Fluorescent whitening agents that give a glow to the clothes.

iii) Oxygen bleaches, such as 'sodium perborate', enable the removal of certain stains from the cloth.

iv) Sodium sulphate is added to prevent the caking of the detergent powder.

v) Enzymes are added to break down some stains caused by biological substances like blood and vegetable juice.

vi) Certain chemicals that give out a pleasant smell are also added to make the clothes fragrant after they are washed with detergents.

11.9.3 Cleansing action of soap

A soap molecule contains two chemically distinct parts that interact differently with water. It has one **polar end**, which is a ***short head*** with a carboxylate group (–COONa) and one **non-polar end** having the ***long tail made of the hydrocarbon chain***.

IQ168L

The polar end is ***hydrophilic (Water loving)*** in nature and this end is attracted towards water. The non-polar end is ***hydrophobic (Water hating)*** in nature and it is attracted towards dirt or oil on the cloth, but not attracted towards water. Thus, the hydrophobic part of the soap molecule traps the dirt and the hydrophilic part makes the entire molecule soluble in water.

When a soap or detergent is dissolved in water, the molecules join together as clusters called '**micelles**'. Their long hydrocarbon chains attach themselves to the oil and dirt. The dirt is thus surrounded by the non-polar end of the soap molecules (Figure 11.3). The charged carboxylate end of the soap molecules makes the micelles soluble in water. Thus, the dirt is washed away with the soap.

Advantages of detergents over soaps

Detergents are better than soaps because they:

- can be used in both hard and soft water and can clean more effectively in hard water than soap.
- can also be used in saline and acidic water.
- do not leave any soap scum on the tub or clothes.
- dissolve freely even in cool water and rinse freely in hard water.
- can be used for washing woollen garments, where as soap cannot be used.
- have a linear hydrocarbon chain, which is biodegradable.
- are active emulsifiers of motor grease.
- do an effective and safe cleansing, keeping even synthetic fabrics brighter and whiter.

Biodegradable and Non-biodegradable detergents:

a) Biodegradable detergents:

They have straight hydrocarbon chains, which can be easily degraded by bacteria.

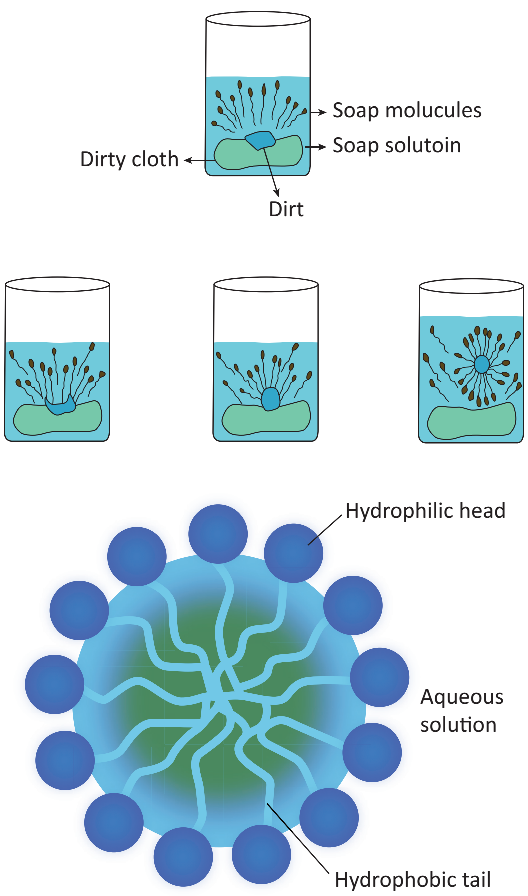


Figure 11.3 Cleansing action of soap

b) Non-biodegradable detergents:

They have highly branched hydrocarbon chains, which cannot be degraded by bacteria.

Disadvantages of Detergents

1. Some detergents having a branched hydro-carbon chain are not fully biodegradable by micro-organisms present in water. So, they cause water pollution.
2. They are relatively more expensive than soap.

11.9.4 Comparison between soap and detergents

Soap	Detergent
It is a sodium salt of long chain fatty acids.	It is sodium salts of sulphonic acids.
The ionic part of a soap is $-COO^{-}Na^{+}$.	The ionic part in a detergent is $-SO_3^{-}Na^{+}$.
It is prepared from animal fats or vegetable oils.	It is prepared from hydrocarbons obtained from crude oil.
Its effectiveness is reduced when used in hard water.	It is effective even in hard water.
It forms a scum in hard water.	Does not form a scum in hard water.
It has poor foaming capacity.	It has rich foaming capacity.
Soaps are biodegradable.	Most of the detergents are non-biodegradable.

Have you noticed the term "TFM" in soap

TFM means TOTAL FATTY MATTER. It is the one of the important factors to be considered to assess the quality of soap. A soap, which has higher TFM, is a good bathing soap.

Points to Remember

- A group or class of organic compounds related to each other by a general molecular formula constitutes homologous series.
- The IUPAC name of the any organic compound consist of three parts. **ROOTWORD, PREFIX and / or SUFFIX.**
- Functional group may be defined as an atom or group of atom or reactive part which is responsible for the characteristic properties of the compounds
- Ethanoic acid is most commonly known as acetic acid and belongs to a group of acids called carboxylic acids.
- Acetic acid is present in many fruits and it renders a sour taste to those fruits.
- Ethanol or ethyl alcohol or simply alcohol is one of the most important members of the family of alcohols.
- The slow chemical change that takes place in complex organic compounds by the action of enzymes leading to the formation of simple molecules is called fermentation.
- Soaps are sodium or potassium salts of some long chain carboxylic acids.
- Detergents are sodium salts of sulphonic acids. Thus instead of $-COOH$ group in soaps, detergents contain $-SO_3H$ group

10th_Science_Unit-11.indd 169 21-02-2019 18:40:59

TEXTBOOK EVALUATION

IQA2A9

I. Choose the best answer.

1. The molecular formula of an open chain organic compound is C_3H_6. The class of the compound is
   a. alkane b. alkene
   c. alkyne d. alcohol

2. The IUPAC name of an organic compound is 3-Methyl butan-1-ol. What type compound it is?
   a. Aldehyde b. Carboxylic acid
   c. Ketone d. Alcohol

3. The secondary suffix used in IUPAC nomenclature of an aldehyde is ____
   a. - ol b. – oic acid
   c. - al d. - one

4. Which of the following pairs can be the successive members of a homologous series?
   a. C_3H_8 and C_4H_{10}
   b. C_2H_2 and C_2H_4
   c. CH_4 and C_3H_6
   d. C_2H_5OH and C_4H_8OH

5. $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ is a
   a. Reduction of ethanol
   b. Combustion of ethanol
   c. Oxidation of ethanoic acid
   d. Oxidation of ethanal

6. Rectified spirit is an aqueous solution which contains about ________ of ethanol
   a. 95.5 % b. 75.5 %
   c. 55.5 % d. 45.5 %

7. Which of the following are used as anaesthetics?
   a. Carboxylic acids b. Ethers
   c. Esters d. Aldehydes

8. TFM in soaps represents ____________ content in soap
   a. mineral b. vitamin
   c. fatty acid d. carbohydrate

9. Which of the following statements is wrong about detergents?
   a. It is a sodium salt of long chain fatty acids
   b. It is sodium salts of sulphonic acids
   c. The ionic part in a detergent is $-SO_3^-Na^+$
   d. It is effective even in hard water.

II. Fill in the blanks

1. An atom or a group of atoms which is responsible for chemical characteristics of an organic compound is called _____________.
2. The general molecular formula of alkynes is _______________
3. In IUPAC name, the carbon skeleton of a compound is represented by __________ (root word / prefix / suffix)
4. (Saturated / Unsaturated) ____________ compounds decolourize bromine water.
5. Dehydration of ethanol by conc. Sulphuric acid forms ________ (ethene/ ethane)
6. 100 % pure ethanol is called _____________
7. Ethanoic acid turns ________ litmus to __________
8. The alkaline hydrolysis of fatty acids is termed as _______________
9. Biodegradable detergents are made of __________(branched / straight) chain hydrocarbons

III. Match the following

Functional group –OH	-	Benzene
Heterocyclic	-	Potassium stearate
Unsaturated	-	Alcohol
Soap	-	Furan
Carbocyclic	-	Ethene

IV. Assertion and Reason:

Answer the following questions using the data given below:

i) A and R are correct, R explains the A.

ii) A is correct, R is wrong.

iii) A is wrong, R is correct.

iv) A and R are correct, R doesn't explains A.

1. **Assertion**: Detergents are more effective cleansing agents than soaps in hard water.

   Reason: Calcium and magnesium salts of detergents are water soluble.

2. **Assertion**: Alkanes are saturated hydrocarbons.

   Reason: Hydrocarbons consist of covalent bonds.

V. Short answer questions

1. Name the simplest ketone and give its structural formula.
2. Classify the following compounds based on the pattern of carbon chain and give their structural formula: (i) Propane (ii) Benzene (iii) Cyclobutane (iv) Furan
3. How is ethanoic acid prepared from ethanol? Give the chemical equation.
4. How do detergents cause water pollution? Suggest remedial measures to prevent this pollution?
5. Differentiate soaps and detergents.

VI. Long answer questions

1. What is called homologous series? Give any three of its characteristics?
2. Arrive at, systematically, the IUPAC name of the compound: $CH_3–CH_2–CH_2–OH$.
3. How is ethanol manufactured from sugarcane?
4. Give the balanced chemical equation of the following reactions:

   (i) Neutralization of NaOH with ethanoic acid.

   (ii) Evolution of carbon dioxide by the action of ethanoic acid with $NaHCO_3$.

   (iii) Oxidation of ethanol by acidified potassium dichromate.

   (iv) Combustion of ethanol.

5. Explain the mechanism of cleansing action of soap.

VII. HOT questions

1. The molecular formula of an alcohol is $C_4H_{10}O$. The locant number of its –OH group is 2.

   (i) Draw its structural formula.

   (ii) Give its IUPAC name.

   (iii) Is it saturated or unsaturated?

2. An organic compound 'A' is widely used as a preservative and has the molecular formula $C_2H_4O_2$. This compound reacts with ethanol to form a sweet smelling compound 'B'.

   (i) Identify the compound 'A'.

   (ii) Write the chemical equation for its reaction with ethanol to form compound 'B'.

   (iii) Name the process.

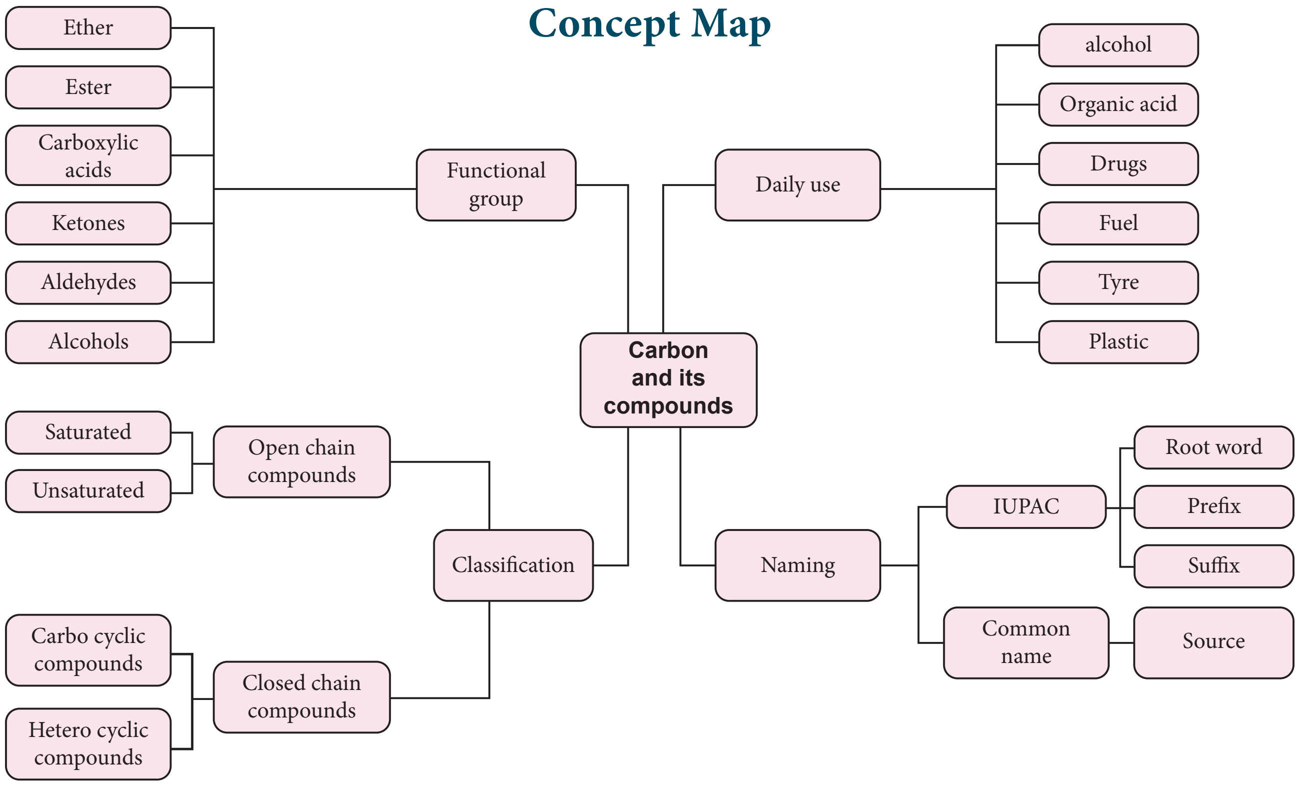
REFERENCE BOOKS

1. Organic chemistry - B.S.Bahl & Arun Bahl S.Chand publishers, New delhi.
2. Organic chemistry - R.T.Morrision & R.MN. Boyd - Prentice Hall Publishers. New Delhi

INTERNET RESOURCES

https://www.tutorvista.com/
https://www.topperlearning.com/
http://www.chem4kids.com/

Concept Map



ICT CORNER

Organic Carbon and its Compounds

The students can know about the Hydrocarbons, its formulae, descriptions and also in animated form.

Steps

- Type the URL or use the QR code to access the application “Organic chemistry visualized / OCV” and install in the mobile.
- Click ‘Content’ to view the list of Hydrocarbon. Explore about the hydrocarbons by clicking those.
- On clicking ‘**anim**’ button, you can view the formulae of hydrocarbon as well as in animated form.
- Click ‘**Quiz**’ to evaluate yourself in this topic.

Step1 **Step2** **Step3** **Step4**

URL: https://play.google.com/store/apps/details?id=com.budgietainment.oc

or Scan the QR Code.

B375_10_SCIENCE_EM

*Pictures are indicative only