PHYSICS
TEST – 6 Part –4

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10th Standard
Unit 1: Laws of 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 speedsup 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.

Mechanicsis the branch of physics that deals with the eff ect 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.

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 infl uence 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 diff ernt mass bodies are dropped from a height, the heavier body falls faster than the lighter one.

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

(i) Th e 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. Th is property of bodies is called 'inertia'.

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

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. Th is is due to, any body would like to continue to be in its state of rest or the state of motion. Th is 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 infl uenced upon by an external unbalanced force, is known as **'inertia'.**

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

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 tochange 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.

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).

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

$p = m v$. . . . .

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}.

NEWTON'S LAWS OF MOTION

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.

Force

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

- produces or tries to produce the motion of a static body.
- stops or tries to stop a moving body.
- 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.

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.**

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.

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**'.

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	$F_{net} = F_1 - F_2$ ($F_1 = F_2$) $F_{net} = 0$

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.

The axis of the fixed edge about which the door is rotated is called as the '*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*'.

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.

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

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

$$M = F \times S. \dots\dots\dots\dots (1.3)$$

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 andnegative if it is rotate in the clockwise direction. They are shown in Figures 1.4 (a and b)

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.

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, atequilibrium, the algebraic sum of the moments of all the individual forces about any point is equal to zero

In the illustration given in figures 1.5, the force F1 produces an anticlockwise rotation at a distance d1 from the point of pivot P (called fulcrum) and the force F2 produces a clockwise rotation at a distance d2 from the point of pivot P. The principle of moments can be written as follows:

Moment in = clockwise direction	Moment in anticlockwise direction

$F1 \times d1 = F2 \times d2$ . . . .

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 Pi = mu

Final momentum of the body Pf = mv

Change in momentum Δp = Pf –Pi
= mv – mu

By Newton's second law of motion,

Force, F ∝ rate of change of momentum

F ∝ change in momentum / time

$F \propto mv-mu/t$
$F=k\, m(v-u)/t$

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

F =m(v-u)/t

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

F = m × a

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

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 × 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

$J = \Delta p$

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.

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).

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.

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

Proof:

Let two bodies A and B having masses m1 and m2 move with initial velocity u1 and u2 in a straight line. Let the velocity of the first body be higher than that of the second body. i.e., u1>u2. 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 v1 and v2 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

$$F_A = -F_B$$

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

$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$ (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.

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).

GRAVITATION

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.

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

$F \propto m_1 x\ m_2/r^2$

$F= G\ m_1\ m_2/r^2$…………(1.10)

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

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.

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

$F= G\ M\ m/R^2$……….. (1.11)

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

$mg = GMm/R^2$------------(1.13)

Acceleration due to gravity

$g = GM/R^2$--------------- (1.14)

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

M = 5.972 × 1024 kg

Variation of acceleration due to gravity (g):

Since, g depends on the geometric radius of the Earth, ($g \propto 1/R2$), 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.

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}. Thisis 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.

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.

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

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?

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 = Fnet = ma R = W + ma	W – R = Fnet = ma R = W - ma R = mg - ma	Here, the acceleration is zero a = 0	Here, the acceleration is equal to g

R = mg + ma **R = m(g+a)**	**R = m(g-a)**	R = W **R= mg**	a = g **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**.

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.

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.

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 $= 40 \times 0.9 = 36$ N m.

Problem 3 : At what height from the centre of the Earth the acceleration due to gravity will be 1/4th 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: $g = GM/R^2$

$g/g' = (R'/R)^2 = (R+h/R)^2 = (1+h/R)^2$

$4 = (1+h/R)^2$,

$2 = 1+h/R$ or $h=R$. $R' = 2R$

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

10th Standard
Unit 2: Optics

INTRODUCTION

Light is a form of energy which travels in the form of waves. Th e 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?' Defi nitely, 'NO'. We can see the objects only when the light is made to fall on the objects and the light refl ected from the objects is viewed by our eyes. You would have studied about the refl ection 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.

PROPERTIES OF LIGHT

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

- Light is a form of energy.
- Light always travels along a straight line.
- Light does not need any medium for its propagation. It can even travel through vacuum.
- The speed of light in vacuum or air is, $c = 3 \times 10^8\ ms^{-1}$.
- 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).
- Different coloured light has different wavelength and frequency.
- Among the visible light, violet light has the lowest wavelength and red light has the highest wavelength.

- When light is incident on the interface between two media, it is partly reflected and partly refracted.

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.

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.

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.

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.

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'.

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,

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'.

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

1) Rayleigh scattering
2) Mie scattering
3) Tyndall scattering
4) 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".

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

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.

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.

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

- **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.

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:

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. Th e 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).

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).

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).

REFRACTION THROUGH A CONVEX LENS

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

Object at infinity

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

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. Th e size of the image is the same as that of the object (Figure 2.7)

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. Th e size of the image is the same as that of the object (Figure 2.8).

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).

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).

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).

APPLICATIONS OF CONVEX LENSES

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

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).

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).

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).

APPLICATIONS OF CONCAVE LENSES

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

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.

SIGN CONVENTION

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

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

- The distances measured downward and perpendicular to the principal axis is taken as negative.

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 theheight 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,

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

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

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

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.

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; $R1$ and $R2$ are the radii of curvature of the two faces of the lens; f is the focal length of the lens.

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.

Unit 3. Thermal Physics

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.

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).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: $[K] = (F + 460) \times 5/9$

$$0\ K = -273°C.$$

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.

- 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.

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.

Characteristic features of heat energy transfer

- Heat always flows from a system at higher temperature to a system at lower temperature.

- The mass of a system is not altered when it is heated or cooled.

- 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

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.

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.

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:
  - Linear expansion
  - Superficial expansion
  - 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.

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

$$\Delta L / L_o = \alpha_L \Delta T$$

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.

$$\Delta A / A_o = \alpha_A \Delta T$$

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.

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

$$\Delta V / V_o = \alpha_V \Delta T$$

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

Vo - Original volume

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

αV - Coefficient of cubical expansion.

- Different materials possess different coefficient of cubical expansion.The following table gives the coefficient of cubical expansion for some common materials.

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.

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 L1. Now, heat the container and the liquid using a burner.

- 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 L2.

- 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 L3. Now, the difference between the levels L1 and L3 is called as **apparent expansion,** and the difference between the levels L2 and L3 is called **real expansion**. The real expansion is always more than that of apparent expansion.

Real expansion = L3 – L2
Apparent expansion = L3 – L1

FUNDAMENTAL LAWS OF GASES

- The three fundamental laws which connect the relation between pressure, volume and temperature are as follows:
    - Boyle's Law
    - Charles's law
    - Avogadro's law

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.

$$P \propto 1/V$$

- 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

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.

$V \alpha T$
or
V/T= constant

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.

i.e. $V \alpha n$
(or) V/N= constant

- Avogadro's number (NA) is the total number of atoms per mole of the substance. It is equal to 6.023 × 1023 /mol.

GASES

- Gases are classified as real gases and ideal gases.

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.

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.

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,**

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

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, NA.

  i.e. $n = \mu NA$. (3.5)

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

  $PV/\mu NAT = constant$

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

  $PV/\mu NAT = kB$

  $PV = \mu NA\ kB\ T$

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

  8.31 J mol−1 K−1.

  $PV = RT$ (3.6)

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

Points to Remember

- v The SI unit of heat energy absorbed or evolved is joule (J)
- v Heat always flows from a system at higher temperature to a system at lower temperature.
- v Temperature is defined as the degree of hotness of a body. The SI unit of temperature is kelvin (K).
- v 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.

v 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 ml – 50 ml = 1.2ml
Real expansion = $L_3 - L_1$
= 51.2 ml – 48.5ml = 2.7ml

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 (V1 cc) to V2 cc. Find the final volume V2.

Data:

Initial pressure (P1)= P
Final Pressure (P2) = 4P
Initial volume (V1) = 20cc = 20cm3
Final volume (V2) = ?

Using Boyle's Law, PV = constant

$$P_1V_1 = P_2V_2$$

$$P_1 / P_2 \times V_2 = V_1$$

$$= P/4P \times 20cm^3$$

$V_2 = 5\ cm^3$

10th Std

Unit-4Electricity

INTRODUCTION

- You have already learnt about electricity in your lower classes, haven't you? Well, electricity deals with the fl ow of electric charges through a conductor. As a common term it refers to a form of energy. Th e 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. Th erefore, 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.

ELECTRIC CURRENT

- The motion of electric charges (electrons) through a conductor (e.g., copper wire) will constitute an electric current. Th is is similar to the fl ow of water through a channel or fl ow 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.

Definition of electric Current

- Electric current is oft en termed as 'current' and it is represented by the symbol 'I'. It is defined as the rate of fl ow of charges in a conductor. Th is means that the electric current represents the amount of charges fl owing 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 fl owing through the conductor is

$$I = \frac{Q}{t}$$

SI unit of electric current

- The SI unit of electric current is ampere (A). Th e current fl owing through a conductor is said to be one ampere, when a charge of one coulomb fl ows across any cross-section of a conductor, in one second.

$$\text{Hence, 1 ampere} = \frac{1\text{coulomb}}{1\,second}$$

Solved Problem-1

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

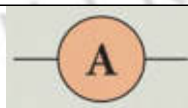
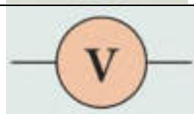
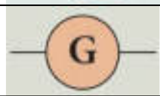
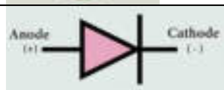
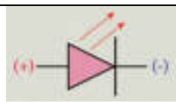
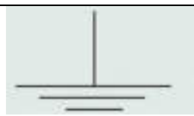
Solution:

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

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

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 fl ow. Th is 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.

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 diff erence.	
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.

v ***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.

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.

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.

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.

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.

- 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:

$$\text{Potential Difference (V)} = \frac{workdone(w)}{charge\ (Q)}$$

- Potential difference is also equal to the difference in the electric potential of these two points. If VA and VB 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 = VA – VB (if VA is more than VB)
V = VB – VA (if VB is more than VA)

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.

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

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

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.

- 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.

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

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

Therefore, I =$\frac{1}{R}$ V

V = I R

- 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.

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.

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 ohm =, $\frac{1volt}{1ampre}$

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

ELECTRICAL RESISTIVITY & ELECTRICAL CONDUCTIVITY

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, $R = \rho \frac{L}{A}$

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

$$\text{From equation } \rho = \frac{Ra}{L}$$

If L = 1 m, A = 1 m2 then, from the above equation ρ = 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.

Nichrome is a conductor with highest resistivity equal to 1.5 × 10–6 Ω m. Hence, it is used in making heating elements.

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.

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 m2, 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 m2

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

$= 4 \times 10^{-8}$ Ω m

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

Conductivity, $\sigma = \frac{1}{\rho} = \frac{1}{4 \times 10{-}8} = 0.25 \times 10{-}8$ mho m–1

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.

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.

- Let, three resistances R1, R2 and R3 be connected in series (Figure 4.6). Let the current flowing through them be I. According to Ohm's Law, the potential differences V1, V2 and V3 across R1, R2 and R3 respectively, are given by:

$V_1 = I R_1$
$V_2 = I R_2$
$V_3 = I R_3$

- 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

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

- 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,

$V = I R_S$ (4.11)

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

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

$R_S = R_1 + R_2 + R_3$ (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
$Rs = R_1 + R_2 + R_3$, $Rs = 5 + 3 + 2 = 10$, hence $Rs = 10\ \Omega$
The current, $I = \frac{V}{Rs} = \frac{10}{10} = 1$ A

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.

- Consider that three resistors R1, R2 and R3 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 I1, I2 and I3 passing through R1, R2 and R3 respectively.

According to the Ohm's law, you have,

$I1 = \frac{V}{R1}$ $R_1R_2\ R_3$

$I2 = \frac{V}{R2}$

$$I3 = \frac{V}{R3}$$

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

$$I = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$$

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

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

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

$$\frac{V}{Rp} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$$

$$\frac{1}{Rp} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

- 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 $\frac{R}{n}$.

$$\frac{1}{Rp} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} ... + \frac{1}{R} = \frac{n}{R}.$$

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

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

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 R1 and R2 be connected in parallel to give an effective resistance of RP1. Similarly, let R3 and R4 be connected in parallel to give an effective resistance of RP2. Then, both of these parallel segments are connected in series (Figure 4.8).

Using equation (4.18), you get

$$\frac{1}{Rp1} = \frac{1}{R1} + \frac{1}{R2}$$

$$\frac{1}{Rp} = \frac{1}{R3} + \frac{1}{R4}$$

Finally, using equation (4.12), the net effective resistance is given by Rtotal = RP1 + RP2

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 R1 and R2 be connected in series to give an effective resistance of RS1. Similarly, let R3 and R4 be connected in series to give an effective resistance of RS2. Then, both of these serial segments are connected in parallel (Figure 4.9).

.no	CRITERIA	SERIES	PARALLEL
	Equivalent resistance	More than the highest resistance.	Less than the lowest resistance.
	Amount of current	Current is less as effective resistance is more.	Current is more as effective resistance is less.
	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

RS1 = R1 + R2, RS2 = R3 + R4

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

$$\frac{1}{R_{total}} = \frac{1}{R_{S1}} + \frac{1}{R_{s2}}$$

Comparison between series and parallel connections

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

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.

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

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

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

$$H = I2\,R\,t \quad (4.20)$$

- 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.

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 = I2Rt, H = 62 × 5 × 300. Hence, H = 54000 J

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:

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

P = V I (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.

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 volt × 1 ampere = 1 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.

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.

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 × 106 J

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.

- 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. represents 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.

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.

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.

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.

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.

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.

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.

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 andan 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.

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.

Unit – 5 ACOUSTICS

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.

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

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

Longitudinal Waves

- Sound waves are longitudinal waves that can travel through any medium (solids,liquids, gases) with a speed that dependson the properties of the medium. As soundtravels through a medium, the particles of the medium vibrate along the direction ofpropagation 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.

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., wavesproduced by bats.

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 ms–1 at NTP	Light waves travel in air with a speed of 3 × 108 ms–1.

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 ms-1.

Particle velocity:

- The velocity with which the particles of the medium vibrate in order to transfer the energyin 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.

∴ Velocity =Distance/Time taken

- If the distance travelled by one wave istaken 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

$$\therefore V = \lambda / T \quad (5.1)$$

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

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

- 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, $v_S > v_L > v_G$

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.

v /√ 1d

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:

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

- Here, v_o is the velocity of sound in the gas at 0° C. For air, $v_o = 331\ ms^{-1}$. Hence, the velocity of sound changes by $0.61\ ms^{-1}$ 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

s.no	Nature of the medium	Name of the medium	Speed of sound (in ms^{-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	331
8		Air	343

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 ischaracterized 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.

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.

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.

- 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.

- The sound waves that travel towards the reflecting surface are called the incident waves. The sound wavesbouncing 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 reflectingsurface.

- 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’ .

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

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. 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.

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 densercompared to water for sound)

Reflection of sound in plane and curved surfaces

- When sound waves are reflected from aplane surface, the reflected waves travel in adirection, 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.

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.

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 dueto 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.

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:

Velocity = distance travelled by sound / time taken

$$V = 2d/t$$

$$d = vt/2$$

Since, t = 0.1 second, then $d = v \times 0.1/2 = v/20$

- 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 ms^{-1},the minimum distance required to hear anecho is 17.2 m.

- 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 ms–1,the minimum distance required to hear an echo is 17.2 m.

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 developingEmbryo or fetus in the mothers uterus.This is a safe testing tool, as it does not useany harmful radiations.

- Echo is used to determine the velocity of sound waves in any medium.

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 soundwave is given by:

Speed of sound =distance travelled/time taken = 2d/t.

APPLICATIONS REFLECTION OF SOUND

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.

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.

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.

DOPPLER EFFECT

- The whistle of a fast moving train appears to increase in pitch as it approaches a stationary listener and it appears to decreaseas 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 thesource 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

- For simplicity of calculation, it is assumed that the medium is at rest. That is the velocityof the medium is zero.Let S and L be the source and the listener moving with velocities vS and vL respectively.

- Consider the case of source and listener moving towards each other (Figure 5.7). As the distance between them decreases, the apparentfrequency will be more than the actual source frequency.

- 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

$$n' = (v + v L / v - vs)n$$

- 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

s.no	Position of source and listener	Note	Expression for apparent frequency
1	1.Both source and listener move 2.They move towards each other	a)Distance between source and listener decreases. b)Apparent frequency is more than actual frequency	$n' =(v+vL/v-vs)n$
2	1.Both source and listener move 2.They move away from each other	Distance between source and listener increases. b) Apparent frequency is less than actual frequency. c) vS and vL become opposite to that in case-1.	n′=v-(vL/v+vs)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) vS becomes opposite to that in case-2.	n' = (v – vL/v – vs)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)vS and vL become opposite to that in case-3.	$n' =(v + Vl/v + vs)n$
5	Source at rest Listener moves towards the source	a)Distance between source and listener decreases. b)Apparent frequency is more than actual frequency.	$n' =(v + vL/v) n$

		c) vS = 0 in case-1.	
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) vS = 0 in case-2.	*n' =(v – vL/v) 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) vL = 0 in case-1.	*n' =(v/v – vs)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) vL = 0 in case-2.	*n'=(v/v + vs)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).

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 thesame as the source frequency.

(i) When source (S) and listener (L) both areat 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.

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 bya 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 frequencychange, 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.

10th std
Unit – 6 NUCLEAR PHYSICS

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 andGoldstein 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.

RADIOACTIVITY

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.

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 elementswith the emission of radiations like alpha, beta, and gamma rays is called 'radioactivity' and the elements, which undergo this phenomenon are called 'radioactive elements'.

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.

There have been 29 radioactive substances discovered so far. Most of them are rare earth metals and transition metals.

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, whichis 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.

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.

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 × 1010 disintegrations in one second. This is actually close to the activity of 1 g of radium 226.

1 curie = 3.7 × 1010 disintegrations per second.

Rutherford (Rd):

It is another unit of radioactivity. It is defined as the quantity of a radioactive substance, which produces 106 disintegrations in one second.

1 Rd = 106 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.

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.

Uranium, named after the planet Uranus, was discovered by Martin Klaproth, a German chemist in a mineral called pitchblende.

Properties of Alpha, Beta and Gamma rays

These three particles possess certain similarities and dissimilarities in their properties.

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:

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.

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.

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.

$${}_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4} \text{ (} \alpha \text{ - decay)}$$

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.

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.

$${}_{15}P^{32} \rightarrow {}_{16}S^{32} + {}_{-1}e^{0} \text{ (} \beta \text{ - decay)}$$

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.

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.

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.

NUCLEAR FISSION

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})

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q \text{ (energy)}$$

The average energy released in each fission process is about 3.2×10^{-11} J.

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 fissionwhereas 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.

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:

1. controlled chain reaction and
2. uncontrolled chain reaction.

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.

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.

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 (mc)'. 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'.

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.

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.

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 us 1eV = 1.602×10^{-19} joule. ing an electric potential of one volt. 1 million electron volt = 1 MeV = 10^6 eV (mega electron volt) The energy released in a nuclear fission process is about 200 MeV.

NUCLEAR FUSION

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.

Definition

The process in which two lighter nuclei combine to form a heavier nucleus is termed as 'nuclear fusion'.

E.g.: ${}_1H^2 + {}_1H^2 {}_2He^4 + Q$ (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.

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 3×10^8 ms^{-1}.

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.

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.

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'.

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.

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.

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).

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.

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.

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.

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 andprevent 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.

Medicine

Medical applications of radio isotopes can be divided into two parts:

1. Diagnosis
2. 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.

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.

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.

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.

How old is our mother Earth? Any guess?? It is nearly 4.54 × 109 years (around 45 Crore 40 lakh years). Wow!!

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.

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.

Preventive measures

1. Radioactive materials should be kept in a thick walled lead container.
2. Lead coated aprons and lead gloves should be used while working with hazardous radioactive materials.
3. You should avoid eating while handling radioactive materials.
4. The radioactive materials should be handled only by tongs or by a remote control device.
5. Dosimeters should be worn by the users to check the level of radiation.

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.

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.

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.

Fuel:

A fissile material is used as the fuel. The commonly used fuel material is uranium.

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.

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.

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.

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.

Uses of a nuclear reactor

1. Nuclear reactors are widely used in power generation.
2. They are also used to produce radio isotopes, which are used in a variety of applications.
3. Some reactors help us to do research in the field of nuclear physics.
4. Breeder reactors are used to convert non-fissionable materials into fissionable materials.

Nuclear power plants in India

Indian Atomic Energy Commission (AEC) was established in August 1948 by theDepartment 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

Identify A, B, C, and D from the following nuclear reactions.

$${}_{13}Al^{27} + A \rightarrow {}_{15}P^{30} + B$$

$${}_{12}Mg^{24} + B \rightarrow {}_{11}Na^{24} + C$$

$${}_{92}U_{238} + B \rightarrow {}_{93}Np^{239} + D$$

Solution:

$${}_{13}Al^{27} + {}_{2}He^{4} \rightarrow {}_{15}P^{30} + {}_{0}n^{1}$$
$${}_{12}Mg^{24} + {}_{0}n^{1} \rightarrow {}_{11}Na^{24} + {}_{1}H^{1}$$
$${}_{92}U^{238} + {}_{0}n^{1} \rightarrow {}_{93}Np^{239} + {}_{-1}e^{0}$$

A is alpha particle, B is neutron, C is proton, and D is electron

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 Bq = one disintegration per second one curie = 3.7×10^{10} Bq

$$1\ \text{Bq} = \frac{1}{3.7 \times 10^{10}}\ \text{curie}$$
$$\therefore 3.7 \times 10^3\ \text{G Bq} = 3.7 \times 10^3 \times 10^9 \times \frac{1}{3.7 \times 10^{10}}$$
$$= 100\ \text{curie}$$

${}_{92}U^{235}$ 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

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) = 3×10^8 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

10th STD

7.ATOMS AND MOLECULES

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 wereremoved and a new theory known as the modern atomic theory was put forward. **'The main postulates of modern atomic theory'** are as follows:

1. An atom is no longer indivisible (after the discovery of the electron, proton, and neutron).
2. Atoms of the same element may have different atomic mass. (discovery of isotopes $_{17}Cl^{35}$, $_{17}Cl^{37}$).
3. Atoms of different elements may have same atomic masses (discovery of Isobars $_{18}Ar^{40}$, $_{20}Ca^{40}$).
4. Atoms of one element can be transmuted into atoms of other elements. In other words, atom is no longer indestructible (discovery of artificial transmutation).
5. 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).
6. Atom is the **smallest particle that takes part in a chemical reaction.**
7. 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.

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).

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 Ar. It is otherwise called "Standard Atomic Weight".

Relative Atomic Mass

$$(\text{Ar}) = \frac{\text{Average mass of the isotopes of the element}}{\frac{1}{12^{th}} \text{ of the mass of one Carbon-12 atom}}$$

- 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.

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

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

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 usconsider 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

- 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.

Atomic Number	Name	Symbol	Atomic Mas (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.

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

oxygen = (15.9949 × 0.99757) + (16.9991 ×0.00038) + (17.9992 × 0.00205)
= 15.999 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

$$\text{boron} = \left(10\times\frac{20}{100}\right)+\left(11\times\frac{80}{100}\right)$$

$$= (10 \times 0.20) + (11 \times 0.80)$$

$$= 2 + 8.8$$

$$= 10.8 \text{ amu}$$

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.

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'.

- 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 elementsthat exist as diatomic molecules are hydrogen (H_2), nitrogen (N_2) and halogens: fluorine (F_2), chlorine (C_{l2}), bromine (Br_2) and iodine (I_2).

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 %)	

- Ozone (O3) 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.

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)

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.

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 (H2SO4) 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 × 1) + (1 × 32) + (4 × 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 (H2O) 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 × 1) + (1 × 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.

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.

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

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

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 × 1023
= Number of Molecules / 6.023 × 1023

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 takingthe example of H_2O. It can be calculated using the formula

  Mass % of an element

$$= \frac{\text{mass of that element in the compound}}{\text{molar mass of the compound}} \times 100$$

molar mass of H2O = 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 $CH4$ = 12 + 4 = 16 g

Mass % of carbon = $\frac{12}{16}\times 100$ = 75 %

Mass % of hydrogen = $\frac{4}{16}\times 100$ = 25 %

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 thenumber 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 dm3) 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.

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.

APPLICATIONS OF AVOGADRO'S LAW

1. It explains Gay-Lussac's law.
2. It helps in the determination of atomicity of gases.
3. Molecular formula of gases can be derived using Avogadro's law
4. It determines the relation between molecular mass and vapour density.
5. It helps to determine gram molar volume of all gases (i.e, 22.4 litre at S.T.P)

RELATIONSHIP BETWEEN VAPOUR DENSITY AND RELATIVE MOLECULAR MASS

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.

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

$$= \frac{\text{Mass of 'n' molecules of a gas or vapour at S.T.P}}{\text{Mass of 'n' molecules of hydrogen}}$$

- 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.

$$= \frac{\text{Mass of 1 molecule of a gas or vapour at S.T.P.}}{2 \times \text{Mass of 1 atom of hydrogen}}$$

Relative molecular mass (hydrogen scale)

$$= \frac{\text{Mass of 1 molecule of a gas or vapour at STP}}{\text{Mass of 1 atom of hydrogen}}$$

- 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

SOLVED PROBLEMS
I. Calculation of molar mass

- Calculate the gram molar mass of the following.
- H_2O
- CO_2
- $Ca_3 (PO_4)_2$

Solution:
1) H_2O
Atomic masses of H = 1, O = 16

Gram molar mass of H_2O = (1 × 2) + (16 × 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 × 1) + (16 × 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 × 3) + [30 + (16 × 4)] × 2
= 120 + (94 × 2) = 120 + 188
Gram molar mass of $Ca_3(PO_4)_2$ = 308 g

Calculation based on number of moles from mass and volume

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

5.6 litre of oxygen at S.T.P

$$\text{Number of moles} = \frac{\text{Given volume of } O_2 \text{ at S.T.P}}{\text{Molar volume at S.T.P}}$$

$$\text{Number of moles of oxygen} = \frac{5.6}{22.4} = 0.25 \text{ mole of oxygen}$$

Calculate the number of moles of a sample that contains 12.046 × 1023 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

Calculation of mass from mole
Calculate the mass of the following

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

2.24 litre of SO_2 gas at S.T.P

Molecular mass of SO_2= 32 + (16 × 2) = 32 + 32 = 64

$$\text{Number of moles of } SO_2 = \frac{\text{Given volume of } SO_2 \text{ at S.T.P}}{\text{Molar volume } SO_2 \text{at S.T.P}}$$

$$\text{Number of moles of } SO_2 = \frac{2.24}{22.4} = 0.1 \text{ mole}$$

$$\text{Number of moles } = \frac{\text{Mass}}{\text{Molecular mass}}$$

Mass = No. of moles × molecular mass
Mass = 0.1 × 64
Mass of SO_2 = 6.4 g

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 × 10^{23} / 6.023 × 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

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

Calculation based on number of atoms/ molecules.

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

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

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

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

Calculation based on molar volume
Calculate the volume occupied by:

2.5 mole of CO_2 at S.T.P

$$\text{Number of moles of } CO_2 = \frac{\text{Given volume at S.T.P}}{\text{Molar volume at S.T.P}}$$

$$2.5 \text{ mole of } CO_2 = \frac{\text{Volume of CO2 at S.T.P}}{22.4}$$

Volume of CO_2 at S.T.P = 22.4 × 2.5 = 56 litres.

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 × 22.4
= 44.8 litres at S.T.P

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 × 22.4
= 11.2 litres

Calculation based on % composition

Calculate % of S in H_2SO_4
Molar mass of H_2SO_4

= (1 × 2) + (32 × 1) + (16 × 4)
= 2 + 32 + 64
= 98 g

% of S in $H_2SO_4 = \frac{\text{Mass of sulphur}}{\text{Molar mass of } H_2SO_4} \times 100$

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

10th std

8.PERIODIC CLASSIFICATION OF ELEMENTS

Introduction

- The eighteenth and nineteenth centuries witnessed a rapid developmentin 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.

MODERN PERIODIC LAW

- Mendeleev's periodic table had some discrepancies, which were difficultto 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. 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 ofelements 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".

MODERN PERIODIC TABLE

- With reference to the modern periodic law, the elements were arrangedin 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.

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

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 (1s1). 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.

PERIODIC TRENDS IN PROPERTIES

- The electronic configurations of elements help us to explain the periodicrecurrence 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.

Atomic Radius

- Atomic radius of an atom is defined as the distance between the centreofits 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.

- In non-metallic elements, their atomic radius is known as Covalentradius. It is defined as half the distance between the nuclei of two covalently bonded atoms of the same element in a molecule. For example, let us consider H2 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.

- 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.

Ionic Radii

- It is defined as the distance from the centre of the nucleus of the ionupto 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.

- For instance, lithium and sodium lose the single electron from theiroutermost 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.

Ionisation Energy

- Ionisation energy is the minimum energy required to remove anelectron 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 energyis 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.

As the positive charge increases the size of the cation decreases As thenegative charge increases the size of the anion increases

Electron Affinity

- Electron affinity is the amount of energy released when a gaseous atomgains an electron to form its anion. It is also measured in kJ/mol and represented by the following equation:

  $A(g) + e^{-} \rightarrow A^{-(g)}$ + Energy
  $Cl(g) + e- \rightarrow Cl^{-}_{(g)}$+ energy
- Like ionisation energy, electron affinity also increases from left to rightin a period and decreases from top to bottom in a group.

Electronegativity

- Electronegativity of an element is the measure of the tendency of itsatom 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.

- Electronegativity is based on various experimental data such as bondenergy, 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.
  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, thebond 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, theelectronegativity 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

METALLURGY

- Human life is associated with various metals. We use metals in our dayto 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 andmodifying 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:

- **Concentration or Separation of the ore:** It is the process of removal of impuries from the ore.

- **Production of the metal:** It is the convertion of the ore into metal.

- **Refining of the metal:** It is the process of purification of the metal

Terminology in metallurgy

- **Minerals:** A mineral may be a single compound or a complex mixture ofvarious compounds of metals found in the Earth.

- **Ore:** The mineral from which a metal can be readily and economicallyextracted on a large scale is said to be an ore.

- **For example:** Clay (Al2O3. 2 SiO2. 2 H2O) and bauxite (Al2O3.2 H2O) 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 iscalled mining.

- **Gangue or Matrix:** The rocky impurity associated with an ore is calledgangue or matrix.

- **Flux:** It is the substance added to the ore to reduce the fusiontemperature 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 gangueduring the extraction of metals.

  Flux + Gangue → Slag

- **Smelting:** Smelting is the process of reducing the roasted metallic oxidefrom the metal in its molten condition. In this process, impurities are removed as slag by the addition of flux.

Types of separation or concentration of an ore

- There are four major types of separation of ores based on the nature ofthe ore. The different kinds of ores of metals.

Hydraulic (Gravity Separation) method

- **Principle:** The difference in the densities or specific gravities of the oreand 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 tablewith 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.

Magnetic separation method

- **Principle:** The magnetic properties of the ores form the basis ofseparation. When either the ore or the gangue is magnetic, this method is employed. e.g., Tinstone SnO_2, the ore of tin.

- **Method:** The crushed ore is placed over a conveyer belt which rotatesaround 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.

Froth floatation

- **Principle:** This process depends on the preferential wettability of the orewith 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).

- **Method:** The crushed ore is taken in a large tank containing oil andwater 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).

Chemical method or Leaching

This method is employed when the ore is in a very pure form.

Oxide Ores	**Carbonate Ores**	**Halide Ores**	**Sulphide ores**
Bauxite ($Al_2O_3.2H_2O$)	Marble ($CaCO_3$)	Cryolite (Na_3AIF_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)

- The ore is treated with a suitable reagent such that the ore is soluble in itbut 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.

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.

PROPERTIES OF METALS
Physical properties

- **Physical state:** All metals are solids at room temperature except mercury and gallium.

- **Lustre:** Metals possess a high lustre (called metallic lustre).

- **Hardness:** Most of the metals are hard and strong (exceptions: sodium and potassium can be cut with a knife)

- **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).

- **Density:** Metals have a high density (exceptions: sodium and potassium are less dense than water).

- **Ductility:** Metals are usually ductile. In other words, they can be drawn into thin wires without breaking.

- **Malleability:** Metals are usually malleable, i.e, they can be beaten into thin sheets without cracking (except zinc and mercury).

- **Conduction of heat and electricity:** Metals are good conductors of heat and electricity; silver and copper excel in this property (exception: tungsten)

- **Solubility:** Usually, metals do not dissolve in liquid solvents.

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.

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	$Al_2O_3.2H_2O$
Cryolite	Na_3AlF_6
Corundum	Al_2O_3

- Bauxite is the chief ore of aluminium. The extraction of aluminium from bauxite involves two steps:

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.

$$2Al(OH)_3 \xrightarrow{1000°c} Al_2O_3 + 3H_2O$$

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: $2 Al_2O_3 \rightarrow 4 Al + 3 O_2\uparrow$

- 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

- **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.

  $4\ Al + 3\ O_2 \rightarrow 2\ Al_2O_3$(Aluminium oxide)
  $2\ Al + N_2 \rightarrow 2\ AlN$ (Aluminium nitride)

- **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.

  $2\ Al + 3\ H_2O \rightarrow Al_2O_3 + 3\ H_2\uparrow$

- **Reaction with alkalis:** It reacts with strong caustic alkalis forming aluminates.

  $2\ Al + 2\ NaOH + 2\ H_2O \rightarrow 2\ NaAlO_2 + 3\ H_2\uparrow$

- **Reaction with acids:** With dilute and con. HCl it liberates H2 gas.

  $2\ Al + 6\ HCl \rightarrow 2\ AlCl_3 + 3\ H_2\uparrow$

- Aluminium liberates hydrogen on reaction with dilute sulphuric acid. Sulphur dioxide is liberated with hot concentrated sulphuric acid

  $2\ Al + 3\ H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3\ H_2$
  $2\ Al + 6\ H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6\ H_2O + 3\ SO_2\uparrow$

- **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**.

  $Fe_2O_3 + 2\ Al \rightarrow 2\ Fe + Al_2O_3$ + Heat.

Uses

Aluminium is used in

- household utensils
- electrical cable industry
- making aeroplanes and other industrial mechine parts

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	$CuFeS2$
Cuprite or ruby copper	$Cu2O$
Copper glance	$Cu2S$

- 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

- **Concentration of ore:** The ore is crushed and the concentrated by froth floatation process.

- **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.

  $2\ CuFeS_2 + O_2 \rightarrow Cu2S + 2\ FeS + SO_2 \uparrow$

- **Smelting:** The roasted ore is mixed with powdered coke and sand and is heated in a blast furnace to obtain matte (Cu2S + FeS) and slag. The slag is removed as waste.

- **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.

  $2\ FeS + 3\ O_2\ 2\ FeO + 2\ SO_2 \uparrow$
  $FeO + SiO_2\ FeSiO_3$ (slag)
  $2\ Cu_2S + 3O_2\ 2\ Cu_2O + 2\ SO_2 \uparrow$
  $2\ Cu_2O + Cu_2S\ 6\ Cu + SO_2 \uparrow$

- **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:

v **Cathode**: A thin plate of pure copper metal.
v **Anode**: A block of impure copper metal.
v **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

- **Action of Air and Moisture:** Copper gets covered with a green layer of basic copper carbonate in the presence of CO2 and moisture.

  $2\ Cu + O_2 + CO_2 + H_2O \rightarrow CuCO_3.Cu(OH)_2$

- **Action of Heat**: On heating at different temperatures in the presence of oxygen, copper forms two types of oxides CuO, Cu2O.

  $2\ Cu + O_2 \xrightarrow{\text{below 1370K}} 2\ CuO$
  $4\ Cu + O2 \xrightarrow{\text{above 1370K}} 2\ Cu_2O$

Action of Acids:
With dilute HCl and dilute H2SO4:

- Dilute acids such as HCl and H2SO4 have no action on these metals in the absence of air. Copper dissolves in these acids in the presence of air.

  $2\ Cu + 4\ HCl + O_2\ (air)\ 2\ CuCl_2 + 2\ H_2O$

With dil. HNO3:

- Copper reacts with dil. HNO3 with the liberation of Nitric Oxide gas.

  $3\ Cu + 8\ HNO_3 \rightarrow Cu(NO_3)_2 + 2\ NO \uparrow + 2H_2O$
  $Cu + 2\ H_2SO_4 \rightarrow CuSO_4 + SO_2 \uparrow + 2\ H_2O$

Action of Chlorine:

- Chlorine reacts with copper, resulting in the formation of copper(II) chloride.

  Cu + Cl2 CuCl2

Action of Alkalis:

- Copper is not attacked by alkalis.

Uses of Copper:

- It is extensively used in manufacturing electric cables and other electric appliances.
- It is used for making utensils, containers, calorimeters and coins,
- t is used in electroplating.

- It is alloyed with gold and silver for making coins and jewels

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)

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.

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.

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.

- 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.

$$C + O_2 \xrightarrow[\Delta]{1500°C} CO_2 + Heat$$

- It is an exothermic reaction since heat is liberated.

- The Middle Region (Fusion Zone) – The temperature prevails at 1000°C. In this region, CO2 is reduced to CO.

$$CO2 + C \xrightarrow[\Delta]{1000°C} CO_2 + Heat$$

- Limestone decomposes to calcium oxide and CO_2

$$CaCO3 \xrightarrow[\Delta]{} CO2 - Heat$$

- These two reactions are endothermic due to absorption of heat. Calcium oxide combines with silica to form calcium silicate slag.

$$CaO + SiO_2 \rightarrow CaSiO_3$$

- 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:

- It is a lustrous metal, greyish white in colour.
- It has high tensility, malleability and ductility.
- It can be magnetized

Chemical properties:

- **Reaction with air or oxygen:** Only on heating in air, iron forms magnetic oxide.

  $3 Fe + 2 O_2 \rightarrow Fe_3O_4$ (black)

- **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**.

  $4 Fe + 3 O_2 + x H_2O \rightarrow 2 Fe_2O_3 . xH_2O$(rust)

- **Reaction with steam:** When steam is passed over red hot iron, magnetic oxide is formed.

  $3 Fe + 4 H_2O$ (steam) $\rightarrow Fe_3O_4 + 4 H_2 \uparrow$

- **Reaction with chlorine:** Iron combines with chlorine to form ferric chloride.

  $2Fe + 3Cl_2 \rightarrow 2FeCl_3$ (ferric chloride)

- **Reaction with acids:** With dilute HCl and dilute H_2SO_4 it liberates H_2 gas.

  $Fe + 2HCl \rightarrow FeCl_2 + H_2 \uparrow$
  $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2 \uparrow$

- With dilute HNO3 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. H2SO4 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. HNO3 it becomes chemically passive or inert due to the formation of a layer of iron oxide (Fe3O4) 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.

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.

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:

- To modify appearance and colour
- To modify chemical activity.
- To lower the melting point.
- To increase hardness and tensile strength.
- To increase resistance to electricity.

Method of making alloys

- By fusing the metals together. E.g. Brass is made by melting zinc and copper.

- 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).

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

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.

- Rust is chemically known as hydrated ferric oxide (it is formulated as $Fe_2O_3.xH_2O$). Rusting results in the formation of scaling reddish brown hydrated ferric oxide on the surface of iron and iron containing materials.

Types of Corrosion
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.

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.

Methods of preventing corrosion

1. **Alloying:** The metals can be alloyed to prevent the process of corrosion. E.g: Stainless Steel
2. **Surface Coating:** It involves application of a protective coating over the metal. It is of the following types:

Galvanization:

- It is the process of coating zinc on iron sheets by using electric current.

Electroplating:

- It is a method of coating one metal over another metal by passing electric current.

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.

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

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.